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AN EXPLORATORY SIMULATION STUDY OF A HEAD-UP DISPLAY FOR GENERAL AVIATION LIGHTPLANES

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16. Abstract

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SUMMARY

The concept of a simplified head-up display referred to as a landing-site indicator (LASI) for use in lightplanes is discussed. Results of a fixed-base simulation study exploring the feasibility of the LASI concept are presented in terms of measurements of pilot performance, control-activity parameters, and subjective comments of four test subjects. These subjects, all of whom had various degrees of piloting experience in this type aircraft, performed a series of simulated landings both with and without the LASI starting from different initial conditions in the final approach leg of the landing maneuver. The results indicated a general, although not unqualified, acceptance of the LASI concept by the test subjects and demonstrated some beneficial effects accruing from its use. The results showed generally that its use reduced the magnitude and the variations of the pilot performance and control-activity parameters that were measured.

INTRODUCTION

The task of landing an airplane is a complex operation requiring a high degree of pilot training, proficiency, and knowledge of the capabilities and limitations of the specific airplane involved. This task relies heavily on the senses and reflexes of the pilot and is probably the most demanding phase of all the basic flight maneuvers that most pilots are called on to perform. This statement appears to be borne out by the fact that the greatest number of aviation accidents and fatalities are associated with the landing phase of flight, according to the statistics of reference 1. Furthermore, these statistics reveal that the greatest number of these accidents and fatalities occur with single-engine lightplanes involving primarily private pilots with moderate amounts of flight experience; also, these accidents occur most frequently in visual-flight-rules (VFR) weather conditions. Therefore, it appears that studies should be undertaken to investigate methods for simplifying the piloting task for the landing maneuver in general-aviation aircraft.

In recent years significant progress has been made in the development and utilization of complex head-up display systems for military and commercial aircraft to assist the pilot in performing landings during normal and adverse weather conditions. Unfortunately these systems are far too costly and heavy for application in lightplanes; however, a much simpler instrumentation system combined with the head-up display concept appears to offer the potential of improving the private pilot's landing task. The concept for one such system has been developed at the Langley Research Center and studies have been initiated to explore its potential usefulness with particular reference to landing in VFR conditions. The proposed system is called a landing-site indicator and is hereafter referred to as LASI.

This paper discusses the basic concept of the proposed device and describes the results of an exploratory simulation study using experienced pilots as test subjects. The study employed a fixed-base simulator comprised of a cockpit with an out-of-the-window visual scene system showing a representative landing field. This simulator was configured to be somewhat representative of a specific low-wing, single-engine lightplane in use at that time as a flying research vehicle at the Langley Research Center. Flight test results obtained with this vehicle provided the necessary information to ensure that the aircraft dynamic responses provided in the simulator were similar to those of current lightplanes. Four pilots performed a large number of landings both with and without the head-up display starting from various initial conditions in the final leg of the landing approach. The landing performance of the pilots was analyzed to determine the influence of the proposed display in reducing either the magnitude or the variations of some of the significant landing-performance parameters. Measurements of some pilot control-activity parameters were also obtained.

SYMBOLS

h	altitude of airplane above ground, meters
V	airplane airspeed, meters/second
W_C	measure of control-activity parameters, radians^2/second
x	longitudinal distance from beginning of runway, meters
y	lateral distance from runway center line, meters
α	angle of attack, degrees
β	angle of sideslip, degrees

γ flight-path angle, degrees

δ control deflection, radians

$\overline{\delta}$ average of the absolute value of control deflection from trim, radians

η angular distance between actual and desired aim point, degrees

θ pitch attitude of airplane, degrees

φ roll attitude of airplane, degrees

ψ heading of airplane relative to the runway, degrees

Subscript:

0 initial conditions

A dot over a symbol denotes derivative with respect to time.

RECENT DISPLAY DEVELOPMENTS

Over the past few years considerable effort has been expended attempting to develop various forms of display systems to aid the military and commercial airline pilots in performing landings as well as other flight operations. The British have pioneered development of head-up displays (HUD) that provide the pilot with vital information concerning the flight conditions as he is looking through the windshield to acquire visual contact with the landing site (ref. 2). Work has proceeded along the same lines in this country as well and developments have reached the point where such displays have been incorporated in some operational aircraft. Unfortunately, complexity, cost, and weight of these systems are major factors prohibiting their application to the general-aviation category of aircraft and, particularly, to lightplanes.

A major benefit of the various HUD systems is that they permit the pilot to derive information on critical operating parameters while he is looking forward out of his windshield at the landing site. The collimated display symbols allow his eyes to remain focused at or near infinity as he uses the display so that his perception of the ground or other visual references is not significantly impaired. Perhaps the most pertinent benefit, however, for student pilots or those private pilots who fly very little is that the HUD systems can provide information in a format that relates directly to the landing site as viewed through the windshield. Furthermore, only the information that he needs for this task is given and he does not need to rely on visual scanning of unrelated information to find the needed information.

PILOTING TASK

Before proceeding with a description of the LASI concept, a somewhat simplified discussion of the normal piloting task for the landing approach without a landing aid is presented so as to point out the significance of the features of the concept.

This discussion is aided by the diagram of figure 1 which depicts a profile view of an airplane in its final approach leg to a runway under no-wind conditions. The diagram shows some of the linear and angular relationships that are involved. The no-wind condition was chosen for sake of brevity and clarity of discussion inasmuch as the effects of winds do not significantly alter the basic principles and relationships involved. The airplane is shown to be proceeding along its flight path from an altitude h_1 to a lower one h_2 with a constant airspeed V and a glide-path angle γ. The flight path is not normally specified for a given airplane in the pilot's flight manual but can be derived from indicated airspeed and engine speed for a given gross weight and flap setting. These settings also establish the angular relationships of the longitudinal reference of the aircraft (X-axis) to the earth's horizon – the pitch attitude θ – and to the velocity vector of the aircraft – the angle of attack α. For the no-wind condition assumed in this discussion, these relationships are expressed as $\gamma = \theta - \alpha$. Diagrams depicting the views of the runway as seen by the pilot from the cockpit at the two altitudes h_1 and h_2 are given in figure 2. This figure also shows the equivalent linear and angular relationships that are depicted in figure 1. These relationships form the basis for LASI concept and reference should be made to both figures in the following discussions.

The flight path is shown to intersect the runway at point A, that is, the actual point on the surface toward which the airplane is flying. Assume that the pilot decides that point A is too close to the end of the runway and that he has selected point A' as the proper aim point to use so as to permit the airplane to touchdown at a desired spot B. The angular difference, as seen by the pilot, between the actual aim point A and the desired point A' is indicated in the sketches as η_1 at altitude h_1, and as η_2 at altitude h_2. The pilot's task during this portion of the approach can be defined in part by the following sequence:[1]

[1]The discussion is directed toward the problem of longitudinal control of the aircraft. A discussion of the lateral-directional control would follow somewhat similar lines but will not be covered herein for the sake of brevity.

Step a. Establish and maintain nearly steady approach airspeed.

Step b. Determine proper location of aim point A' in relation to desired touchdown point B.

Step c. Detect actual aim point A and determine its position and movement $(\eta_2 - \eta_1)$ relative to the surface.

Step d. Apply appropriate control inputs to cause A to coincide with A', preferably prior to the time the flare initiation altitude is reached.

Step e. Monitor flight conditions of the aircraft to ensure that the operational limits are not exceeded.

In order to perform step a, the pilot must have information as to the magnitude and variation of the airspeed. Normal student-pilot instruction techniques usually emphasize the importance of learning to set up and maintain approach airspeed by use of indirect methods rather than by looking directly at the airspeed indicator on the instrument panel. This seemingly simple and obvious direct method is very undesirable because the pilot usually requires several seconds to refocus his eyes from outside to inside and then back outside. The loss of outside reference for such periods of time is distracting and can cause disorientation as a result of a significant departure from the desired approach conditions while the pilot is distracted. The pilot must rely instead on the indirect cues available in the visual scene, usually pitch attitude, and to audio cues resulting from the airstream, engine, and propeller noises. Such cues are not particularly strong or reliable sources of information concerning airspeed, and they usually require a high degree of familiarity with the particular aircraft in order for the pilot to interpret them. This aspect constitutes one of the problems that imposes a significant workload on the pilot as part of the VFR landing task.

The major problem, however, that normally makes this task most difficult, particularly with student pilots or with experienced pilots who do not fly very regularly, appears to be associated with step c. There is no direct indication available to the pilot as to the actual direction or position of the aircraft velocity vector, point A, in relation to his visual field. Point A can only be inferred by looking for that particular area of the visual scene that appears to be moving directly toward the pilot with no apparent motion vertically and horizontally relative to him. This action requires a significant amount of time and concentration by the pilot. Unfortunately, the pilot has no well-defined reference on the airplane with which to judge this relative motion, and as a result detection of the small angular differences $(\eta_2 - \eta_1)$ involved is considered to be poor even under very good VFR conditions. In addition, this detection can be significantly degraded under these same conditions by compounding factors such as a dirty or fogged windshield and sunglare caused by landing in the direction of the sun.

A common technique employed by pilots in performing step c is to use the nose of the aircraft or a particular spot on the windshield as a reference and to position the desired aim point A' with respect to this so-called "gage" or "eyeball reference." Since the pilot is focusing his attention at the aim point on the runway, this "gage" cannot be seen very clearly because of the extreme differences in distances involved and the inability of the eyes to focus on both near and far objects at the same time. Furthermore, the proper positioning is dependent on several factors and can change significantly as the result of the use of flaps.

The fifth step e constitutes another significant problem area for the pilot as he approaches the runway threshold and becomes increasingly involved in positioning the aircraft properly over the runway. Inasmuch as his visual cues out of the window give no direct indication as to the motion of the aircraft relative to the airmass, the pilot has no way of knowing how close to the stall he is operating. Wing stall is directly related to the angles of attack and flap setting as well as to the sideslip angle. Although angles of attack and sideslip might be inferred by the pilot from the attitude and motions of the aircraft with respect to the surface, such estimates would be subject to gross errors under windy conditions inasmuch as the actual angles are determined by the aircraft motion with respect to the local airmass and not the ground surface.

The conclusion has been drawn from the considerations presented in this brief discussion that the major uncertainties facing the pilot as he approaches the runway under normal VFR conditions are directly related to information concerning the magnitude and direction of the velocity vector with respect to (1) the aircraft, (2) its operating limits, and (3) the runway surface. The LASI system features, therefore, were chosen so as to minimize these uncertainties and to simplify the pilot's task thereby permitting him to make more precise and consistent landings.

LANDING-SITE-INDICATOR CONCEPT

The concept of a simplified landing-site indicator is based on essentially the same principles and benefits of the other HUD-type systems but the implementation is directed toward reductions in system complexity, cost, and weight for application to the general-aviation field. Furthermore, the concept is based on the use of an airborne system that does not require information from the ground other than the direct visual scene so that the pilot may land at any site he selects, including unimproved landing strips and cow pastures. It was hypothesized that such a system could play a significant role in improving the safety record of general aviation if the system's use can be shown to permit private pilots to perform their landing manuevers with greater precision and consistency. Inasmuch as a major portion of the landing accidents occur during VFR conditions, it was decided that the gains to be realized with a simpler system designed strictly for VFR conditions could be worthwhile even though one designed to include instrument-flight-rules (IFR) conditions would have a potential for maximum gains. It was also recognized that the simpler system designed for VFR conditions could possibly serve as a basic element of a more complicated IFR system if the simpler system proved successful in the VFR mode.

System Features

Because of the exploratory nature of this study, only the general features of the system have been considered and no attempt has been made to define specific design details beyond those necessary for an understanding of the concept and implementation of a fixed-based simulator study of the concept.

The primary feature of the LASI is a collimated head-up viewing unit which provides a graphic indication of the aircraft velocity vector with respect to the three specific references discussed in the section entitled "Piloting Task." The sketch in figure 3 is similar to those of figure 2 but shows the pilot's view of the landing site as he looks directly through the proposed viewing unit. The details of the display format represent only an initial stage of development and are discussed herein so as to show the purpose and utilization of the various display elements. The viewing unit is shown mounted in the instrument cowling but could be mounted in any one of the three locations and arrangements depicted by the sketches in figure 4 depending on various human factors and system design requirements for a given airplane.

A schematic diagram of one possible arrangement of the elements of the display unit is given in figure 5 to show generally how the display symbols could be generated and projected into the pilot's field of view. This is done by means of a beam splitter or inclined semireflecting mirror. The display symbols correspond to the magnitude and direction of the aircraft velocity vector and to fixed aircraft reference marks. A collimating lens is used within the unit to focus the display symbols at or near infinity so that the symbols appear as sharply focused images as the pilot focuses his eyes at the runway.

The two digits displayed in the upper-central portion of the view (see fig. 3) correspond to the last two significant numbers of the airspeed as derived from the normal airspeed system of the aircraft. The digital format was selected on the basis of the assumption that the pilot thinks directly in terms of numbers rather than needle position or some other analog display whenever he refers mentally to the required approach speeds. Consequently, the digital display should require less interpretation and be subject to less error than a more conventional display.

Position for the digits was selected so that the numbers would be in the pilot's peripheral field of view and not interfere with his foveal or central vision as he looks at the aim point near the runway threshold. Although the pilot does not look directly at these numbers, he should be warned of significant changes in airspeed as the result of a flickering effect caused by the changing digits. Flickering or motion effects are known to be readily detectable in the parafoveal area of the eye. In this case a low flicker frequency denotes a gradual speed change and a faster frequency denotes a more rapid change. The pilot should be able to interpret these flicker rates in terms of the urgency for scanning or looking directly at the velocity display.

The short fixed line in the central portion of the display directly below the airspeed digits corresponds to the optical ray that is parallel with the longitudinal reference axis of the aircraft. The center of this line is referred to as the zero reference point and corresponds to the point X shown in figures 1 and 2. The primary function of this line is to ensure that the display system is properly alined with the aircraft

The winged circular symbol, hereafter referred to as the α,β-index, is used to show the direction of the velocity vector relative to the aircraft. Under the no-wind conditions as discussed previously, the position of this index also corresponds to the actual aim point A depicted in figures 1 and 2. The index is positioned vertically and horizontally with respect to the zero reference point and moves in response to the measured angles of attack and sideslip, respectively. The signals to drive the α- and β-actuators within the display unit would be derived from some type of flow sensing devices mounted externally on the aircraft. The angular positioning of the index within the unit is scaled directly in a 1:1 relationship with the pilot's visual angles. If the α,β-index coincides with the zero reference point during the flight, the aircraft is flying at zero angles of attack and sideslip and the velocity vector coincides with the longitudinal reference axis. This is a condition that generally corresponds closely to that for normal cruising flight. Although the LASI system could be used for this and other flight conditions, the possible application of LASI as a general flight instrument will not be considered in this discussion.

Two additional fixed lines, the approach and stall references, are located beneath the zero reference point at the vertical positions corresponding to the normal operating and maximum angles of attack for the aircraft in the landing conditions. The long broken line corresponds to the approach angle of attack and the short broken line represents the angle at which stall conditions are first encountered. The lines are longer than the zero reference line to make them readily apparent against the features of the visual scene and to denote the normal allowable ranges of sideslip angles for each angle of attack. Inasmuch as the proper approach and stall angles vary primarily with flap settings, the position of these two lines should be shifted vertically to correspond to specified flap settings. Therefore, when the α,β-index is centered with respect to the approach reference, the aircraft will be flying at zero angle of sideslip and the proper angle of attack for whatever flap setting is being used.

If the α,β-index deviates in the downward direction and crosses the stall reference line, the airplane is flying in a stalled condition and loss of control may result unless corrective action is taken. Likewise, if the index deviates laterally beyond the reference line similar problems may be encountered as the result of excessive sideslipping.

Piloting Technique With LASI

The basic technique to be used by the pilot with LASI in performing the landing approach task can be described briefly, in terms of the previously outlined steps, as follows:

Step a. Adjust flaps and power to normal specific settings to establish nominal approach conditions; move elevator and rudders to center α,β-index between the approach reference lines, and continue to monitor index position to ensure that it stays within the normal operational limits of the aircraft as defined by the reference lines; observe airspeed display to determine that essentially steady approach velocity has been achieved.

Steps b and c. Observe position and motion of α,β-index relative to the desired aim point on the runway.

Step d. Adjust power and aircraft heading so as to cause the index to coincide with the desired aim point.

Step e. Adjust elevator and rudder only if any significant changes in airspeed or angles of attack and sideslip occur.

As the flare altitude is reached, generally between 5 and 15 meters above the runway, engine power will be reduced and the elevator will be pulled back gradually. The LASI display permits the pilot to monitor the gradual bleed-off of airspeed and increase in angle of attack as the aircraft continues to descend toward the selected touchdown point. In fact, with some practice the pilot can use the LASI to initiate and control the flare so that the aircraft will automatically touch down at the desired point. In this case, he merely moves the elevator control so as to shift and maintain the α,β-index from the approach aim point to the desired touchdown point.

Normally under low wind conditions, the touchdown point should be selected so that the aircraft just reaches its stall angle of attack as ground contact is made. This ensures that the touchdown velocity will be as low as practical so as to reduce tire wear and minimize landing roll-out problems. Under windy conditions, it is necessary to make the approach and flare at higher speeds (lower angle of attack) than normal to ensure that gusty conditions will not cause an inadvertent stall and loss of control. Inasmuch as LASI provides a direct indication to the pilot of the actual angle-of-attack variations in relation to the stall conditions throughout the landing, he should be able to use these indications to establish the appropriate landing speeds under any wind condition.

The influences of headwinds and crosswinds can be treated fairly easily by noting that the α,β-index determines the aim point relative to the airmass. Since wind is the motion of the airmass relative to the earth's surface, the effect of wind is to cause the apparent aim point as defined by α,β-index to move across the terrain with the direction and velocity of the wind. Consequently, if the pilot holds the normal steady approach conditions, he will observe the α,β-index drifting in the downwind direction toward the actual aim point as determined by the aircraft velocity relative to the ground. In this case, therefore, he knows that either he must "lead" the desired aim point with the α,β-index in the upwind direction or else he must alter his α- and β-conditions so that the α,β-index remains steady at the desired aim point. If the pilot elects to "lead" the aim point, he will establish a condition where the α,β-index slowly drifts in the downwind direction and intercepts the aim point as the airplane approaches the flare-initiation altitude. He can accomplish this by his conventional techniques of crabbing or sideslipping.

SIMULATION STUDY

The simulation study reported herein was an initial attempt to determine the feasibility of the concept in terms of the pilot's ability to demonstrate some degree of landing-performance improvement with a relatively simple simulation of the LASI system. Very little attempt was made to incorporate improvements beyond the "first-cut" effort. Furthermore, this study did not address the feasibility problem from the standpoint of actual mechanization of the hardware. Details of the lightplane simulator are covered in the appendix. The actual format of the LASI differed somewhat from that described in the previous section; however, the same principles of operation were observed. The differences in format were the result of convenient mechanization of the simulator and are not considered to be significant for the purpose of this study.

TESTS AND TEST SUBJECTS

Inasmuch as the LASI concept was developed for use in general-aviation aircraft, a group of pilots having a variety of experience with this type aircraft was selected and asked to perform a series of landings both with and without the LASI. The landing runs were made into a steady runway crosswind and were started with different initial conditions at a distance from the runway threshold approximately equivalent to the nominal position of the instrument-landing-system (ILS) middle marker on the final approach leg. These landings were terminated during the ground roll-out after touchdown.

Tests

The pilots were placed arbitrarily into two groups in an attempt to minimize any training effects. One group started the test series with the LASI and the second group started the test series without the LASI. Then each group switched after completing the group of landings for the different initial conditions and flew the series in reverse order. Each pilot was allowed as many practice approaches as he felt were necessary before the data runs were carried out. The test series consisted of 20 runs of four different initial conditions presented in a random order with five runs of each condition. For the second test series the random order of the four initial conditions was reversed. Table I shows the four different initial conditions. Case I was a straight-in approach started from the middle marker on the ILS glide slope. Case II began halfway through a left turn from base to final leg at the middle marker. Case III was the same as case II except from a right turn. Case IV was a straight-in approach but 30 meters higher than case I. A steady wind of 4.9 meters per second coming from 20° to the right of the runway was simulated for each landing. Table II shows the test sequence as it was performed in these tests.

The pilot's task was to land the airplane as he normally would in a real airplane. Each test was started from trimmed conditions at the approach speed for the flap position preselected by the pilot. He had the option of using various amounts of flap deflection at any time during the approach. He was allowed to develop his own technique for using the LASI during the practice trials after being given a preliminary briefing on its concept and operating principles.

Test Subjects

Table III shows the pertinent data describing the test subjects used in these tests. The subjects consisted of a professional NASA test pilot with a certified flight instructor rating, an aeronautical engineer who was a former military pilot with limited lightplane experience, an electrical technician active part time as a certified flight instructor with an instrument rating, and an aeronautical engineer who was an active private pilot. Although the LASI concept appears to be useful as a training device, no attempt was made to utilize student pilots in this exploratory study. It was considered adequate for purposes of this study to rely on the subjects with significant flight experience to make judgments as to the training potential of this system.

RESULTS AND DISCUSSION

The results of this investigation are presented, first, in terms of simulated landings without LASI (LASI-off) to illustrate the degree to which the simulator was representative of actual flight. Secondly, the LASI-on data are compared with the LASI-off results to show the influence of the head-up display. Thirdly, comments concerning problems encountered in developing the format of the display are presented along with a discussion of the possible application of LASI to the training of student pilots. Finally, a summary of these results is included with some concluding remarks concerning the further development of the LASI concept.

Simulated Landing Without LASI

Although each of the subjects noted various aspects of the simulator that differed in details from actual aircraft experience, there appeared to be general agreement among them that the simulator provided a reasonable duplication of the handling characteristics of a lightplane and that the landing task was fairly realistic. Perhaps the most pertinent problem with the simulator concerned judgment, based on the visual scene, of height of the aircraft above the runway from the time of flare to touchdown. This problem is common to practically all simulators used for landing studies and does not appear to have a readily available solution. It is interesting to note that, in spite of this shortcoming, the pilots seldom resorted to the instrument panel to obtain additional information concerning their altitude and airspeed during the latter part of the landings. Such procedure of looking at the instruments is generally considered undesirable in actual flight and would have indicated an unacceptable low degree of fidelity if the pilots had found it necessary in this simulation.

The subjects commented that the use of the servo-driven seat to simulate ground contact and roll-out as well as engine vibrations added significantly to the realism of the task. The sharp impulse given the seat at moment of contact provided the subjects with a positive and unmistakable cue that landing contact had been made. Judgment of a good landing was often based on the ability to allow the speed to bleed-off while holding the flare and to make touchdown at about the time the stall warning cue was heard.

Four parameters were used to indicate the landing performance for each of the four pilots. The four parameters used are:

altitude h when passing over the runway threshold

distance x from threshold to touchdown point

the vertical rate $\dot{h}$ at touchdown point

the longitudinal rate $\dot{x}$ at touchdown

The data for all four initial conditions have been lumped together in these results inasmuch as the influence of the initial conditions on these particular parameters was judged to be relatively small. Each parameter was converted to cumulative probability density functions. The mean values (50 percentile) and variations (5 and 95 percentile) of the four parameters are summarized in table IV(a) for the tests performed without the LASI. The 5- and 95-percentile values are used to give an indication of the variation in each parameter instead of standard deviation because all of the data does not appear to be normally distributed.

Based on these values, the landing performances of the four pilots were generally similar and appear to agree reasonably close to what would be expected in actual flight. The altitude at the threshold, where the flare is usually initiated, was in the range of about 5.2 to 8.8 meters (mean values) and touchdown occurred generally from 150 to 250 meters down the runway. The simulated runway was 915 meters long; consequently, all touchdowns were being made well within the first third of the runway. Vertical velocities at touchdown averaged between about 0.8 and 1.0 meter per second but ranged to a maximum of 1.8 meters per second. Recent unpublished data indicate that the average vertical velocity at touchdown of a single-engine, low-wing airplane is about 0.5 meter per second. In view of the aforementioned problem of altitude judgment during the flare, these somewhat larger velocities of the simulator could be expected. This deficiency, however, does not appear to be of sufficient magnitude to invalidate the results of these tests.

Longitudinal touchdown velocities were in the range of 28 to 29 meters per second except for pilot B whose landings were in the range of about 25 meters per second. In the case of the other three pilots some landings were made with flaps up and some with them either halfway or all the way extended. Pilot B performed all of his landings with full flaps; consequently, his velocity range should be lower than those for the others. These touchdown velocities compare favorably with the stall speeds given in the pilot's manual for the airplane used as a model for this simulation. The normal sea-level stall speeds given for maximum gross weight with flaps up and full-down were 30 and 26 meters per second.

Therefore, it appears that the simulator used in this study provided a reasonable representation of an actual airplane insofar as the handling characteristics and piloting task for the final leg of the landing maneuver under normal VFR conditions are concerned.

Simulated Landing With LASI

The results of the simulated landings with LASI are summarized in table IV(b) in the same form as those of the previous table for landings without LASI. A direct comparison of the results for the landings with and without LASI is given in figure 6 which is a plot of the values listed in table IV for each of the four pilots. The mean value of each parameter is denoted by the location of the symbol and the 95- and 5-percentile values by the length of line passing through each symbol. Landings without LASI are denoted by the circular symbol and those with LASI by the square. The corresponding values with and without LASI have been joined by lines to emphasize the influence of the proposed display.

Although this figure does not reveal any startling or dramatic changes due to LASI, the effects noted are for the most part beneficial. In every case except the one for $\dot{h}$ for pilot C, there is either a reduction in the mean value or in the spread between the maximum and minimum values, or a reduction in both. The result implies that use of LASI had the effect of helping the pilot to be more consistent in performing slower landings within a shorter distance.

Test-subject comments.- The nature of the comments from the test subjects indicates that different techniques of using LASI were probably being employed, but no attempt was made to evaluate their relative effectiveness. Both elements of the display, the airspeed numbers and the α,β-index, were utilized to different degrees depending to some extent on the phase of the landing maneuver. Pilot A who started with LASI stated that the airspeed numbers were very useful and their absence was noteworthy during his second series of tests without LASI. He also noted that the α,β-index was employed during the flare and that the display as a whole allowed the approaches to be made more accurately.

Pilot B who also used LASI in the first test series noted use of the α,β-index as a cue for longitudinal positioning of the aircraft relative to the landing site but did not particularly miss the display during the second test series. He was concerned with some cluttering of the visual scene with the display format and with the possibility of pilot fixation on the α,β-index to the detriment of the other visual cues available. This problem of interaction between the display and visual scene has been noted by others and appears to be an area requiring further study.

Pilot C who did not use LASI until the second test series noted beneficial effects of the display for the approach and touchdown but suggested turning off the display to remove it from the visual field before executing the flare. His comment was that he was "playing with the dot (α,β-index) and not flying." This suggested that he may not have developed a suitable technique or sufficiently understood the principles of the display. Furthermore, this could account for the previously noted exception in the $\dot{h}$-data.

Pilot D stated that the airspeed display was very useful especially during the flare. On the other hand he did not particularly like the α,β-index and stated that it was "distracting but reassuring." He also used the fixed reference lines of the display for attitude reference. This, actually, was not intended as part of the basic operational technique for this concept.

Control activity and pilot workload.- At the present time, it is difficult if not impossible to measure all important aspects of pilot performance and relate those to the general handling qualities of an aircraft. However, according to reference 3, some encouraging results have been obtained when dealing with various measures of pilot control activity or the physical workload involved in movement of the flight controls. In the present investigation, the influence of LASI on two control-activity parameters, average deflection and average rate of deflection, for both elevator and aileron control was determined. It appears reasonable to assume that these two parameters could account for at least the portion of the total pilot workload attributable to the pilot's physical and mental effort involved in moving the controls and in holding them in out-of-trim positions.

Average deflection from trim was determined by obtaining the integral of the absolute value of control deflection from trim with respect to time and then dividing by the total time of the particular run. Average rate was determined by dividing the total travel the control moved by the total time of the run. The data for these two parameters are given in figures 7 and 8 for each of the test runs of all four subjects but are separated on the basis of the initial approach conditions. These figures show the values of average control deflection plotted against the average rate for the elevator and aileron controls, respectively. The LASI-off data are denoted by the open symbol and the LASI-on by the crossed symbol. Comparisons of these figures reveal, in general, that the LASI-on data points are clustered closer together than those of the LASI-off data, and that the LASI-on data points are located closer to the origin of the figures. These results are interpreted as showing that the pilot used smaller and more consistent control movements when using the LASI.

To relate these two control-activity parameters more closely to pilot workload for these particular test conditions, the average pilot control force is considered to be a direct function of the average-control-deflection parameter $\bar{\delta}$. This appears to be a fairly valid assumption for the control systems being considered because the airspeed is usually held fairly constant throughout most of the landing approach maneuver. Based on this assumption, therefore, the average pilot physical workload in terms of power exerted by the pilot in each control axis should be a direct function of the two control-activity parameters given in figure 7 or 8. For convenience, the term W_C will be used to represent this pilot control-activity parameter, that is,

$$W_C = \bar{\delta} \times \dot{\delta} \tag{1}$$

For purposes of comparing the present test results, a reference value for W_C was determined for each set of control data. The values of 2×10^{-4} and 12×10^{-4} for the elevator and aileron data, respectively, correspond to the average value of W_C when the data of all four cases for each control are considered together. These reference values are represented by the curves in figures 7 and 8. Thus, on the basis of the assumptions of this analysis, data points which fall above or to the right of these curves represent test runs in which the pilot physical workload due to specific control movements was greater than the average effort for all tests considered as a whole.

The influence of LASI on the pilot control-activity parameter is evidenced in figures 7 and 8 by noting the number of data points for each of the two LASI conditions that fall to one side of the reference curve. This influence is summarized in figure 9 which shows the number of runs (data points) for each case that had control-activity data points for the given control greater than the reference curve in figures 7 and 8.

For either control the data shown in figure 9 for the LASI-on runs are markedly lower than those for the LASI-off runs for all four initial approach conditions. It is interesting to note that if the aileron and elevator runs greater than the reference value of W_C are added together, the sums for LASI-off and LASI-on generally increase from case I to case IV; this implies a corresponding increase in workload. This result is consistent with the general nature of the different initial conditions used for these cases. Case I corresponded to a straight-in, on-course condition for which the pilot merely had to wait until the flare altitude was reached before being confronted with any significant task. Cases II and III were left and right turning-to-final conditions in which the pilot had to level the airplane at the proper time to be on course prior to reaching that altitude; consequently, in both cases he was required to perform an additional task. Case IV was on course but was about 30 meters too high at the start so that the pilot had to work throughout the approach to get back on path and land at the desired spot. This generally involved power reduction, speed reduction, or combinations of both. From this observation, therefore, it appears that the effects of using LASI were beneficial over an appreciable range of pilot workload. Furthermore, this reduction in workload implies that the pilots were not merely "playing" (see "Test-subject comments") with the device as a secondary task but were, in fact, integrating it into their primary task and making the landings easier to perform.

Additional Comments

Display format.- The previously discussed results indicate a generally beneficial influence of the LASI concept on the pilot's landing performance and workload. A rather significant discrepancy has been identified, however, which remains to be evaluated as a fundamental problem. This problem seems to stem from the fact that the collimated display produced a significant change in the subject's visual perception of the airplane motion, particularly about the vertical or yawing axis. Numerous comments have been made by the test subjects and by others who have operated the simulator concerning "excessive" yawing motions primarily when the LASI was being used. Also, as mentioned previously, there were complaints that the display tended to "clutter-up" the scene and be distractive.

A check on this general problem was made by comparing the dynamic responses of the simulator to specific pilot inputs with those of the airplane used as the model for the simulator to ensure that the simulator responses were realistic. A further check was made by looking at motion-picture films taken from the pilot's eye position in the reference airplane while landings were being made in the same manner as with the simulator. These films were viewed side by side with films taken in the simulator without the LASI. It was noted that the two films showed similar motions but also that the airplane films seemed to show yawing motions that were considerably greater than were apparent while seated in the airplane. Inasmuch as this second observation concerned only the airplane motions, it was concluded that the excessive yawing was an optical illusion created by an obvious visual reference fixed to the airplane. Apparently in watching the airplane films, the eyes scanned the edges of the picture as well as the details of the scene and the edges were being interpreted as a set of fixed references just as the LASI reference lines were being used in the simulator. In either case, the eyes apparently tend to fixate on the references, at least part time, so that the scene details appeared to move thereby producing the disturbing effect.

For the normal situation of viewing the terrain from the airplane, the eyes are focused at very long distances in relation to the window frame and nose of the airplane. As a consequence, these airplane features are out of focus and their motions relative to the scene are not as readily apparent so that the observer tends to be less visually aware of the aircraft motions in this situation.

This phenomenon can be demonstrated easily by observing a feature on the opposite wall of the room and moving the head slowly from side to side with one eye closed. In this case, the head motion is not interpreted as motion of the scene. If, however, the feature on the far wall is observed through a mailing tube or rolled-up sheet of paper held up to the eye and moved with the head, the feature will appear to move.

One approach to minimize the problem was attempted for the display prior to its use in this study. An original format consisted of a fixed grid corresponding to vertical and horizontal visual angles in 5° increments. This proved to be completely unsatisfactory very quickly for the reason stated. As a partial solution the vertical grid was completely eliminated and the horizontal lines were reduced in number and size to those used in the study. This simplified format proved to be a significant improvement over the original but apparently was not the final solution based on the test subject's subsequent comments.

This problem should have a major impact on the selection of the optimum format for the displayed information and needs to be given considerable attention in the possible development of the LASI concept.

Application to training.- One possible application for the LASI concept is considered to be its use as a training aid in addition to its role as a normal operational instrument. Recognizing the problem of "teaching old dogs new tricks," there is the likelihood that this "new trick" might find greater acceptance and utility with persons who are taught its use at the beginning of their flying experience rather than with those who would have to modify their "old tricks." It is also possible that, even if this concept does not prove feasible in the normal operational role for the average private pilot, it will find significant utility strictly in the training role wherein the device would help the student to learn the proper piloting technique more readily.

Three of the test subjects, who incidentally were probably representative of the "old dog" category of pilots, were questioned concerning their impressions of the effectiveness as a training device. They were somewhat hesitant in their response apparently because of the problem of bridging the gap between the rather limited simulator experience and the intricacies of pilot training. Concern was expressed, however, about the problem of eye fixation on the display elements to the detriment of the other cues. Two of the subjects considered use of only the airspeed display as being desirable, whereas the third considered use of only the α,β-index as being preferable. From another standpoint, one subject stated that the student should be fairly well along in handling the basic flight maneuvers before being exposed to the display. Other comments indicated that the display should give the student added confidence or assurance as long as he understood its principles but that it might become a crutch that would impede his overall progress.

It is evident from these comments that nothing conclusive regarding training applicability can be drawn from this exploratory investigation. However, considering the general beneficial effects obtained in the tests, the question of training effectiveness appears to be a fruitful area for continued study.

Concept feasibility.- The question of feasibility goes beyond that of merely the beneficial effects on pilot performance and workload. The LASI concept envisions usage of relatively low cost elements based on recent advances in miniaturization of electronic, fluidic, and mechanical elements of various industrial and consumer products. Those elements considered applicable are components such as those used in vest-pocket digital computers and in precision radio-control equipment for model aircraft, as well as in some of the latest aeronautical systems. The implementation of the concept with such devices is an area that must be considered in depth before feasibility based on practical utility can be established and the subsequent impact on safety can be evaluated.

CONCLUDING REMARKS

The results of this investigation concerning the feasibility of the landing-site-indicator (LASI) concept for use in lightplanes indicate a general beneficial effect of using LASI for visual-flight-rules landing maneuvers. There were mixed reactions from the four subjects concerning various aspects of the concept ranging from very favorable to mildly undesirable. However, taken as a whole, these reactions are construed as indicating general acceptance of the concept. The influences of LASI on the selected landing-performance parameters, although relatively small, were favorable in most cases. The effects of LASI on five pilot-control-activity parameters implied reductions in workload with use of the display. Subjective comments indicated that the device might possibly play a useful role in pilot training but were not conclusive.

Inasmuch as the simulator environment could possibly have produced effects, either favorable or detrimental, on the results of this exploratory investigation, additional efforts directed toward establishing the feasibility of this concept under conditions more closely matching those of actual aircraft operation are required before reaching firm conclusions. It appears, however, that the findings of this study do offer sufficient evidence of beneficial effects to indicate that continued efforts should be fruitful.

The question of feasibility goes beyond that of merely the beneficial effects on pilot performance and workload. The LASI concept envisions usage of relatively low cost elements based on recent advances in miniaturization of electronic, fluidic, and mechanical elements of various industrial and consumer products. Those elements considered applicable are components such as those used in vest-pocket digital computers and in precision radio-control equipment for model aircraft, as well as in some of the latest aeronautical systems. The implementation of the concept with such devices is an area that must be considered in depth before feasibility based on practical utility can be established and the subsequent impact on safety can be evaluated.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., October 3, 1973.

APPENDIX

DESCRIPTION OF LIGHTPLANE SIMULATOR

The lightplane simulator used in this investigation was developed primarily to investigate some of the problems encountered in obtaining realism or fidelity in relatively small, low-cost simulators. It was assembled from existing equipment using current state-of-the-art techniques. The geometric, mass, and aerodynamic parameters used in the math model were obtained from wind-tunnel tests of a low-wing, single-engine lightplane and from flight tests of another lightplane with essentially the same configuration.

Simulation Facilities and Equipment

The simulation required the use of three separate facilities; a digital computer, a simulated lightplane cockpit, and a terrain-scene generating system. The CDC 6600 computer used in this study provided a 135 K memory with five arithmetic units and a 60 bit word. The equations required 7 milliseconds of computer time to process and were performed 32 times a second. Analog signals associated with the cockpit and terrain-scene equipment were interfaced with the computer by means of analog digital conversion units. A listing of the geometric, mass, and aerodynamic characteristics used in the simulator are given in a subsequent section of this appendix.

Cockpit.- The simulated lightplane cockpit utilized an existing fixed-base, multipurpose cockpit designed primarily as a two-seat, multiengine transport cockpit. The left-hand seat station was modified to be somewhat representative of a single-engine lightplane for this project. Figure 10 is a photograph showing the layout of the cockpit. The display instruments are representative of the conventional type for a single-engine airplane equipped for flying VFR and were as follows: airspeed, turn and bank, and rate-of-climb; indicators; altimeter; artificial horizon; heading gyro; engine tachometer; and a clock. The flight controls consisted of a center stick, rudder pedals, a push-pull throttle, and a three-position flaps lever. Trim controls were provided for pitch, roll, and yaw. Audio cues were provided for engine and airstream noises and a stall-onset warning.

The cockpit was designed for fixed-base simulation; however, the pilot's seat was mounted on a pivot located beneath the rear legs to provide a very limited degree of motion in pitch rotation. A hydraulic servo actuator located vertically beneath the front of the seat produced maximum motions of about ± 1 centimeter at the front of the seat. The actuator was driven with signals corresponding to the engine speed and aerodynamic buffet experienced in the stall. Furthermore, when touchdown occurred the seat was displaced upward a distance proportional to the vertical velocity at touchdown and subsequently was moved slowly back to the central position. This action was followed by a small slow oscillation to simulate motions of the aircraft as it continued to run over the runway surface. Amplitudes of the seat drive signals were adjusted to provide the proper "feel" of the various motion effects.

The visual scene was provided on a 0.625-meter color TV monitor and viewed through a two-lens system giving a virtual image focused at infinity. This system provided a visual scene of unity magnification to the pilot. The visual scene had a field of view of 35° vertically and 43° laterally with the lateral center line of the field of view offset 3° to the right on the monitor. (The downward field of view was limited by a viewing mask to correspond to the visual obstruction of the nose of the airplane.)

Terrain-scene generating system.- The visual-scene facility consisted of three units; the model, the drive cart, and the HUD generating equipment. The model (fig. 11) consisted of a 1:300 scale model of a small airport with two 915-meter runways located in a suburban area near a large city. The total scene covered a full-scale area 1800 meters wide and 2400 meters long. The cart (see fig. 12) transported the television camera along the scaled flight path of the airplane for a longitudinal distance of 2500 meters from the end of the runway to 610 meters past the end of the runway. The lateral excursions were limited to 250 meters on either side of the main runway center line thereby limiting the landings to the one runway. The track along which the cart traveled was curved, and, as a consequence, the range of simulated altitudes varied from 125 to 250 meters at the extreme approach end of the longitudinal track to 2.5 to 125 meters over the runway. Touchdown was considered to occur when the pilot's eye level reached the 2.5-meter altitude.

Maximum cart velocities were well within the scaled flight envelope for this simulation study. Maximum longitudinal and lateral scaled velocities were about 90 meters per second and the maximum vertical velocity was 45 meters per second. Automatic protection in the cart drive circuits was used to prevent the camera head from hitting the scene. The optical head of the camera had a travel of 120° in pitch, 360° in roll, and 360° in yaw. The maximum attitude rates were likewise in excess of the rates needed for this simulation, 60° per second in pitch and 120° per second in roll and yaw. The color camera provided a picture with 510 lines and a frame rate of 30 per second.

The simulated LASI display was generated by placing a black and white TV camera in front of a cathode ray tube (CRT) which generated the movable α,β-index. A lucite plate with the reference lines etched in its surface was placed at 45° in front of the CRT face. The lucite plate was edge lighted so that the scribed lines showed in the picture. The

α,β-index was represented by a small circular spot on the CRT face. This spot was driven up and down by angle-of-attack signals and side to side by the angle-of-sideslip signals. The digital velocity display was derived from the face of a lighted digital voltmeter reflecting in the lucite plate. The two TV pictures of the terrain scene and the LASI display were superimposed for transmission via closed-circuit lines to the cockpit.

The display format used in this study was slightly different from that discussed previously although it consisted of the same basic elements: two airspeed digits, three fixed horizontal reference lines, and a movable solid spot corresponding to the α,β-index. The airspeed digits, each 5° high and 3° wide, were centrally positioned 7° above the optical ray corresponding to the reference axis of the aircraft. The numbers were formed by lines approximately 1° thick. The zero reference line was 1° long. The movable α,β-spot was approximately 0.05° in diameter and moved through an α-range that covered the full visual angle through the TV monitor. The β-range was limited to $\pm 10^{\circ}$. Two horizontal lines, each 12° long, were located vertically at positions corresponding to angles of attack of 1° and 6°. The normal approach angle of attack with flaps full-down was developed with the α,β-index positioned halfway between the two longer lines. With the flaps up, the proper index position was on the lower line. Zero sideslip angle was indicated when the index was centered horizontally with respect to the horizontal reference lines.

Normal trimmed flight conditions for the final approach leg were an airspeed of approximately 39 meters per second and a 6° angle of attack with flaps up, and 34 meters per second and 3° angle of attack with flaps full-down. The maximum downward viewing angle of the visual scene and LASI display at the center line of the pilot's seat varied from about 6° to 10° depending on the pilot and his adjustments of the seat positions. Inasmuch as stall occurred at about 12° to 14° for the two flap positions, the α,β-index could not be seen at the stall. However, disappearance of the index at the bottom of the display during the landing flare served as a visual indication that the stall was being approached.

Geometric, Mass, and Aerodynamic Characteristics of the Simulated Lightplane

The lightplane used as the basis for the simulation study of the LASI concept is a single-engine, low-wing aircraft with tricycle-type landing gear. Measured and estimated values for the various geometric, mass, and aerodynamic parameters of this specific aircraft are listed in this section. All forces and moments are referred to the set of stability axes that pass through the center of gravity and are alined with its vertical plane of symmetry and the longitudinal reference axis (X) of the aircraft.

Parameter	Definition	Value
W	weight, newtons	10 600
S	wing area, $meters^2$	14.9
b	wingspan, meters	9.1
$\bar{c}$	mean geometric chord, meters	1.6
I_{xx}	rolling moment of inertia, $kilogram\text{-}meters^2$	1200
I_{yy}	pitching moment of inertia, $kilogram\text{-}meters^2$	1900
I_{zz}	yawing moment of inertia, $kilogram\text{-}meters^2$	2700
I_{xz}	roll-yaw product of inertia, $kilogram\text{-}meters^2$	70
V	airspeed, meters/second	variable
ρ	density of air, $kilogram/meter^3$	variable
p	angular rate about longitudinal body axis, radians/second	variable
q	dynamic pressure $\left(\frac{\rho}{2} V^2\right)$, $newtons/meter^2$	variable
	angular rate about lateral body axis, radians/second	variable
r	angular rate about vertical body axis, radians/second	variable

Parameter	Definition	Value
α	angle of attack, radian	variable
α_0	angle of attack for zero lift, radian	-0.045
β	angle of sideslip, radian	variable
δ_e	stabilator deflection, radian	up 0.35, down 0.07
δ_a	total aileron deflection, radian	±0.52
δ_r	rudder deflection, radian	±0.47
δ_f	flap deflection, radian	0 to 0.78
δ_t	throttle-control deflection, centimeters	0 to 5.7
C_T	thrust coefficient (Thrust/qS)	variable
C_L	lift coefficient (Lift/qS)	variable to max. of 1.10 with $\delta_f = 0$
C_{L_0}	lift coefficient at $\alpha = 0$	0.27
C_{L_α}	change in life coefficient with α	$4.81 + 13.2C_T$
$C_{L_{C_T}}$	change in lift coefficient with C_T	0.20
$C_{L_{\delta_e}}$	change in lift coefficient with δ_e	0.56
$C_{L_{\delta_f}}$	change in lift coefficient with δ_f	0.68
C_{D_0}	drag coefficient at $C_L = 0$	0.04
$C_{D_{\alpha^2}}$	change in drag coefficient with α^2 (induced drag)	2.54

Parameter	Definition	Value
$C_{D_{\delta_f}}$	change in drag coefficient with δ_f	0.10
$C_{D_{\delta_e}}$	change in drag coefficient with δ_e	0.90α
C_{m_0}	pitching-moment coefficient at $\alpha = 0$	0.01
$C_{m_{C_L}}$	change in pitching-moment coefficient with C_L	-0.12
$C_{m_{\delta_e}}$	change in pitching-moment coefficient with δ_e	$-(1.8 + 1.9C_T)$
$C_{m_{\dot{\alpha}}}$	change in pitching-moment coefficient with $\dot{\alpha}\bar{c}/2V$	-13.0
C_{m_q}	change in pitching-moment coefficient with $q\bar{c}/2V$	-26.0
C_{Y_β}	change in side-force coefficient with β	-0.60
$C_{Y_{C_T}}$	change in side-force coefficient with C_T	0.10
$C_{Y_{\delta_r}}$	change in side-force coefficient with δ_r	0.06
C_{Y_p}	change in side-force coefficient with $pb/2V$	-0.15
C_{Y_r}	change in side-force coefficient with $rb/2V$	0.50
C_{l_β}	change in rolling-moment coefficient with β	-0.11
$C_{l_{\delta_a}}$	change in rolling-moment coefficient with δ_a	-0.09

Parameter	Definition	Value
$C_{l_{\delta_r}}$	change in rolling-moment coefficient with δ_r	$0.02 - 0.10\alpha$
C_{l_p}	change in rolling-moment coefficient with $pb/2V$	-0.49
C_{l_r}	change in rolling-moment coefficient with $rb/2V$	0.15
C_{n_β}	change in yawing-moment coefficient with β	0.05
$C_{n_{\delta_r}}$	change in yawing-moment coefficient with δ_r	$-(0.03 + 0.05\alpha - 0.08C_T)$
$C_{n_{C_T}}$	change in yawing-moment coefficient with C_T	-0.03
C_{n_p}	change in yawing-moment coefficient with $pb/2V$	-0.07
C_{n_r}	change in yawing-moment coefficient with $rb/2V$	-0.09

REFERENCES

1. Anon.: Aircraft Accident Reports – Brief Format, U.S. Civil Aviation, Issue Number 2, 1970 Accidents. Rep. No. NTSB-BA-71-3, Nat. Transp. Safety Board, Oct. 1, 1971.

2. Jenney, Larry L.; Malone, Thomas B.; and Schweickert, George A.: Head-Up Displays – A Study of Their Applicability in Civil Aviation. Contract NASW-1940, Matrix Res. Div., URS Systems Corp., Jan. 8, 1971. (Available as NASA CR-117135.)

3. Cooper, George E.; and Harper, Robert P., Jr.: The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities. NASA TN D-5153, 1969.

TABLE I.- INITIAL CONDITIONS

Case no.	V_0, m/sec	γ_0, deg	x_0, m	h_0, m	y_0, m	φ_0, deg	ψ_0, deg
I	38	-3	-950	65	0	0	0
II	38	-3	-950	75	-180	-30	45
III	38	-3	-950	75	+180	+30	-45
IV	38	-3	-950	95	0	0	0

TABLE II.- TEST RUN SEQUENCE

Run no.	Case no.	Run no.	Case no.
1	I	11	I
2	II	12	II
3	IV	13	I
4	III	14	IV
5	I	15	II
6	III	16	III
7	III	17	II
8	IV	18	III
9	I	19	II
10	IV	20	IV

TABLE III.- DESCRIPTION OF TEST SUBJECTS

Subject	Age	Profession	Pilot qualifications	Total flight hours
A	38	Research pilot	Former military pilot (certified flight instructor)	4500
B	40	Aero. engineer	Former military pilot (minimal lightplane)	650
C	29	Elec. technician	Active certified flight instructor	1000
D	36	Aero. engineer	Active private pilot	700

TABLE IV.- MEASURED PERFORMANCE PARAMETERS

(5-, 50-, AND 95-PERCENTILE VALUES)

(a) LASI-off

Pilot	Percentile			Percentile			Percentile			Percentile		
	5	50	95	5	50	95	5	50	95	5	50	95
	h, m			x, m			$\dot{h}$, m/sec			$\dot{x}$, m/sec		
A	2.0	5.2	11.6	37	174	330	0.3	0.9	1.8	25	28	31
B	5.6	6.4	9.0	82	151	208	0.2	0.8	1.4	23	25	27
C	2.6	6.2	13.6	75	192	241	0.4	0.7	1.2	26	28	30
D	3.8	8.6	21.2	99	253	348	0.4	0.9	1.5	24	28	31

(b) LASI-on

Pilot	Percentile			Percentile			Percentile			Percentile		
	5	50	95	5	50	95	5	50	95	5	50	95
	h, m			x, m			$\dot{h}$, m/sec			$\dot{x}$, m/sec		
A	2.1	4.9	7.3	34	116	218	0.5	0.8	1.2	26	27	28
B	2.7	5.5	9.1	55	127	184	0.2	0.6	1.2	25	26	28
C	4.4	8.5	11.8	155	189	222	0.5	1.1	1.7	24	26	28
D	4.4	8.8	13.1	175	206	275	0.8	1.0	1.3	24	28	30

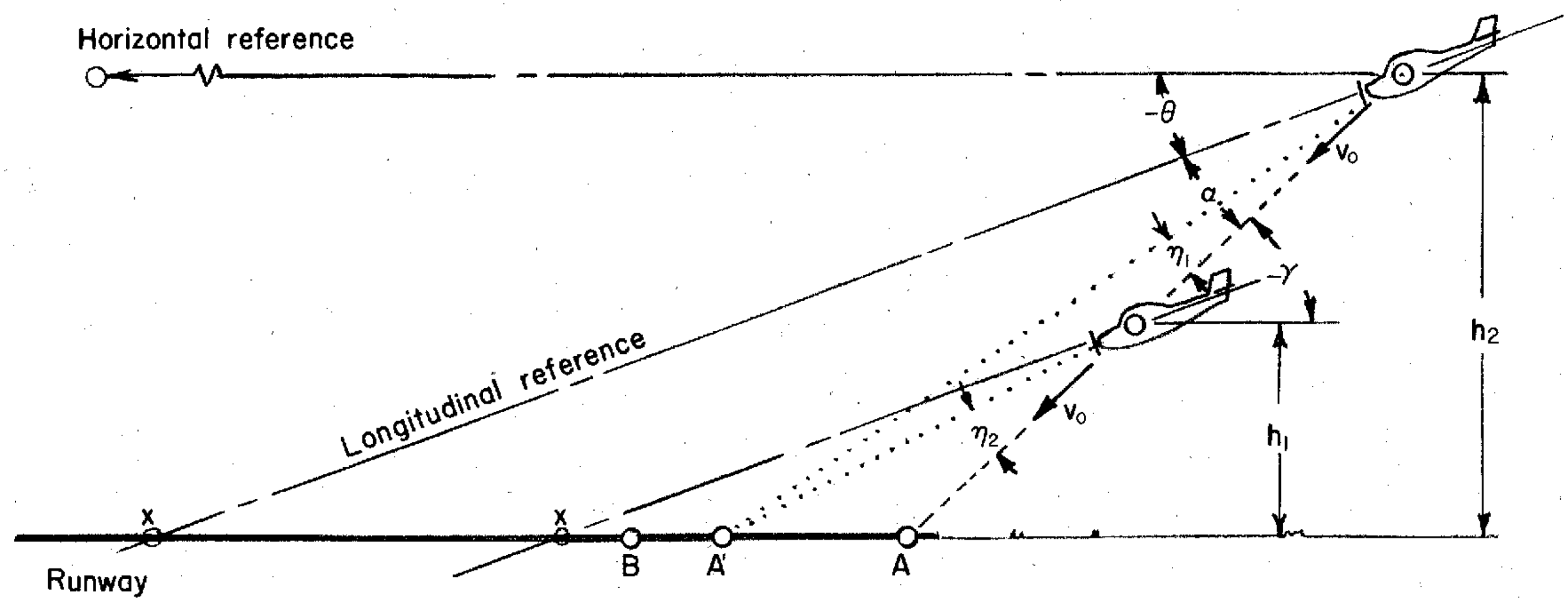


Figure 1.- Sketch showing profile view of airplane during two stages of the final approach leg under no-wind conditions. Point A is the actual aim point and point A' is the desired aim point selected by the pilot to permit a touchdown at point B.

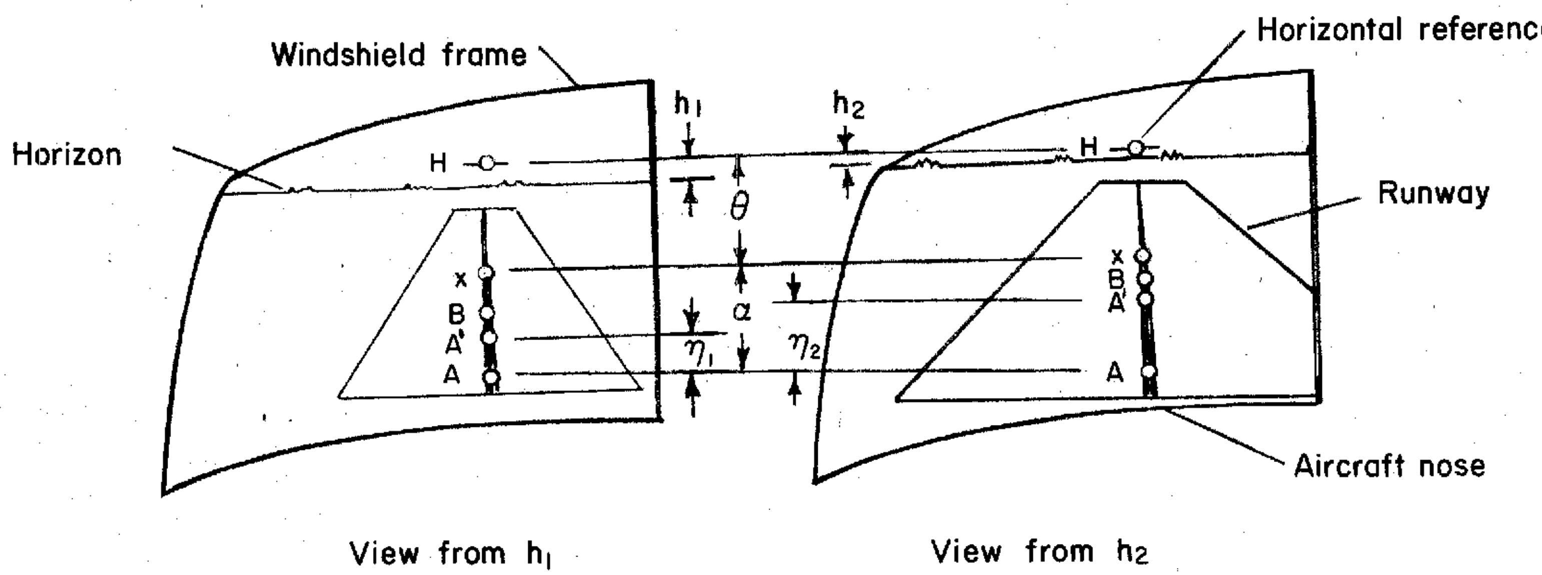


Figure 2.- Diagrams showing the pilot's view from the cockpit at two altitudes h_1 and h_2 during a landing approach. Reference points and equivalent angular relationships given in figure 1 are designated by corresponding symbols.

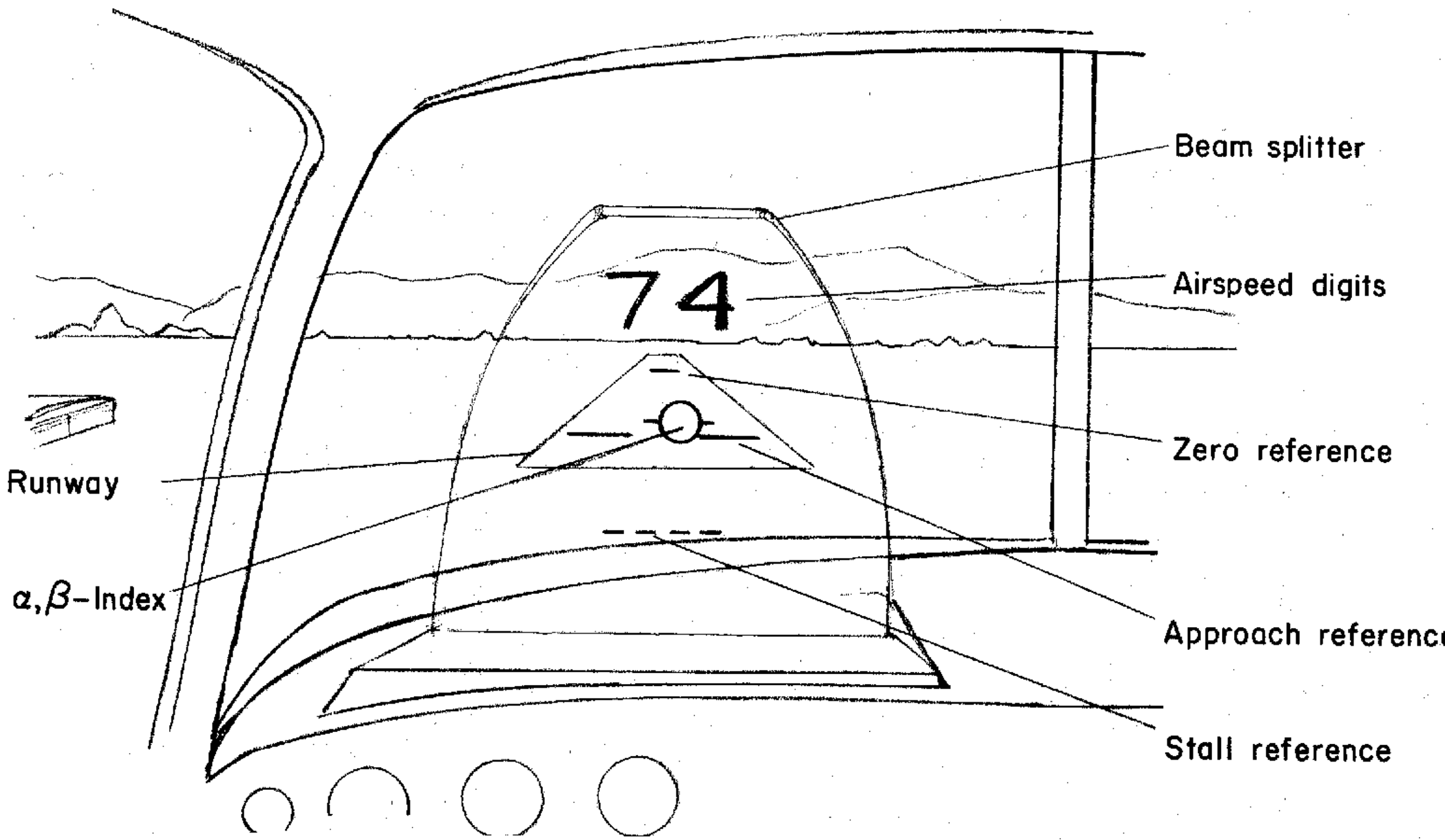
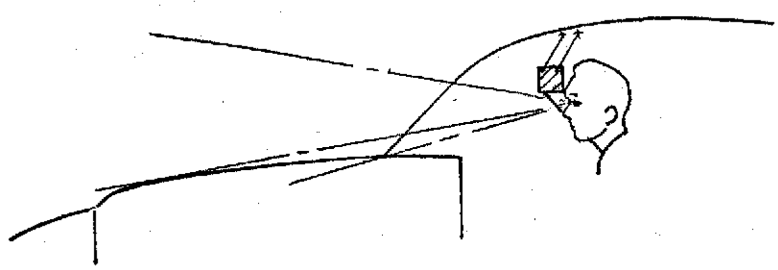
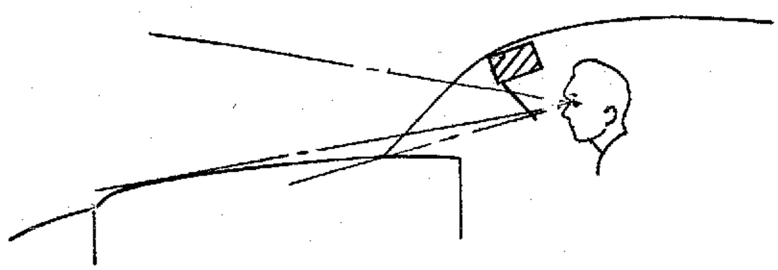


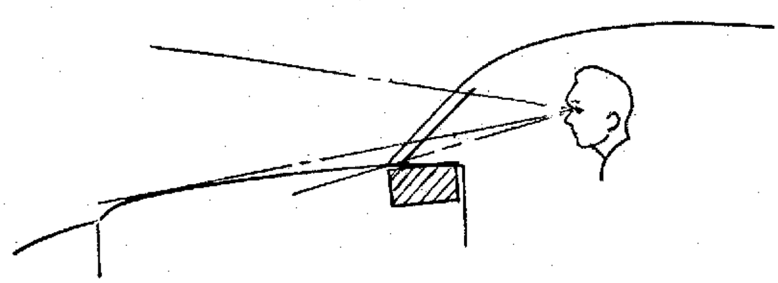
Figure 3.- Sketch showing the pilot's view of a landing site as seen through the LASI display unit. Displayed symbols are focused by internal collimating lens so that the symbols are seen clearly and sharply as the pilot looks at the runway or other distant features.



Monocular – Overhead



Binocular – Overhead



Binocular – Cowl

Figure 4.- Sketches depicting three possible mounting arrangements of an LASI display unit.

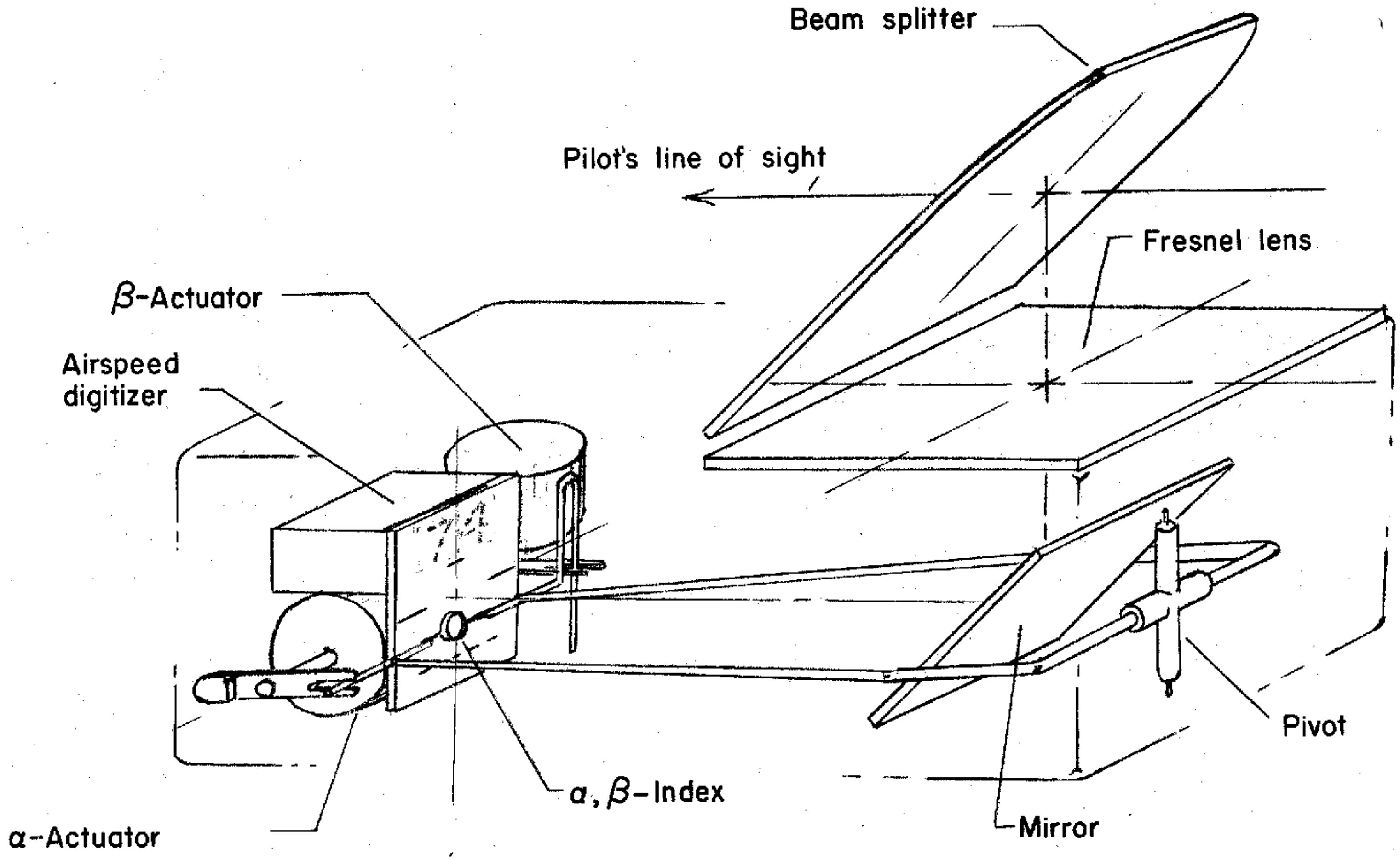
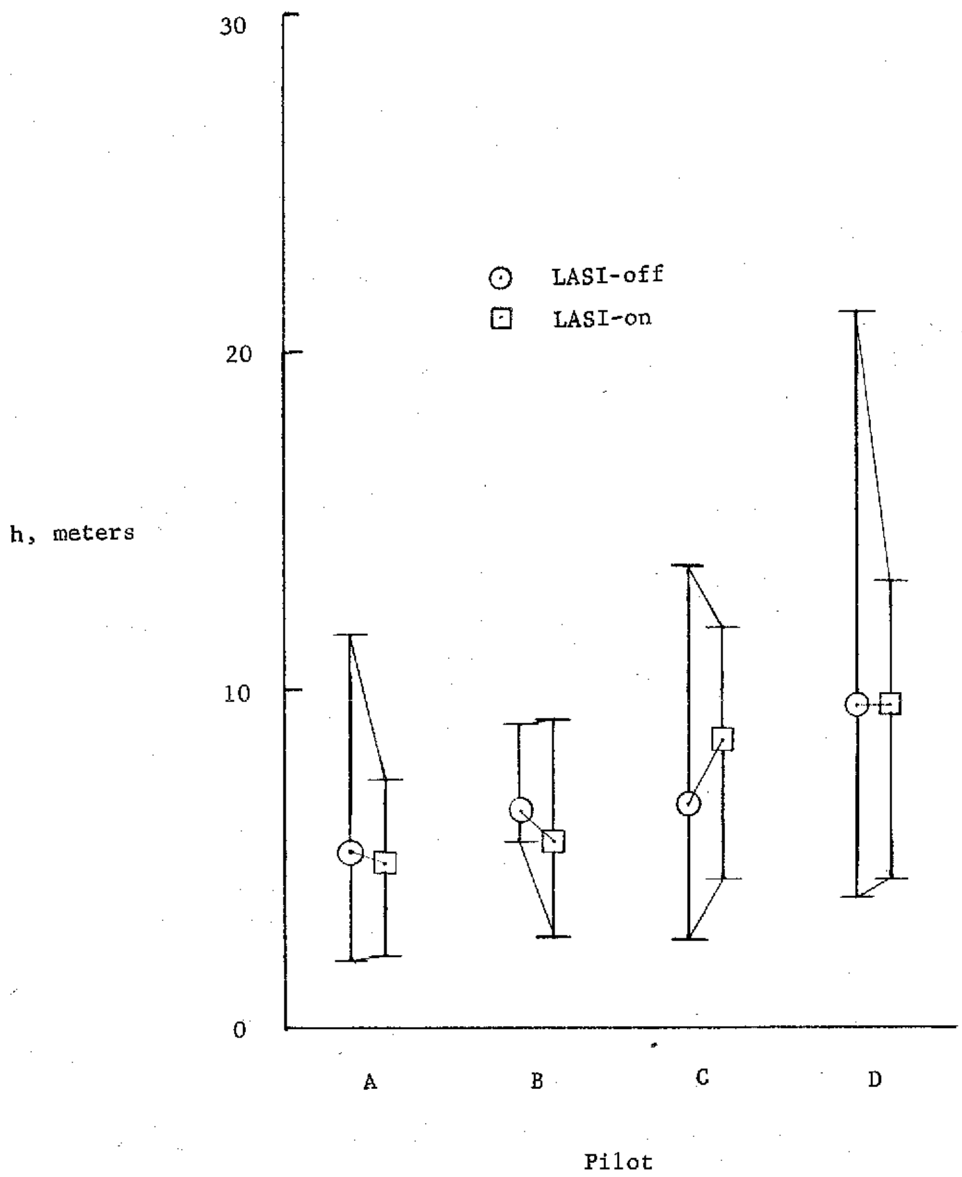
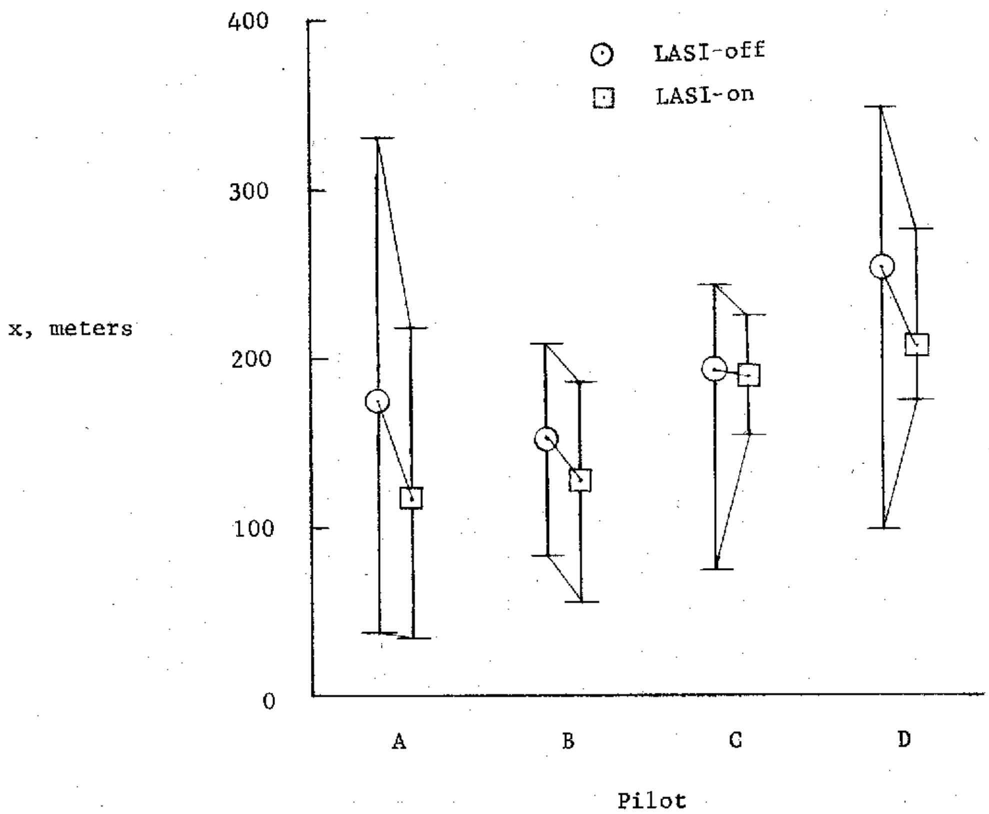


Figure 5.- Schematic diagram of a possible arrangement of the LASI display unit elements.



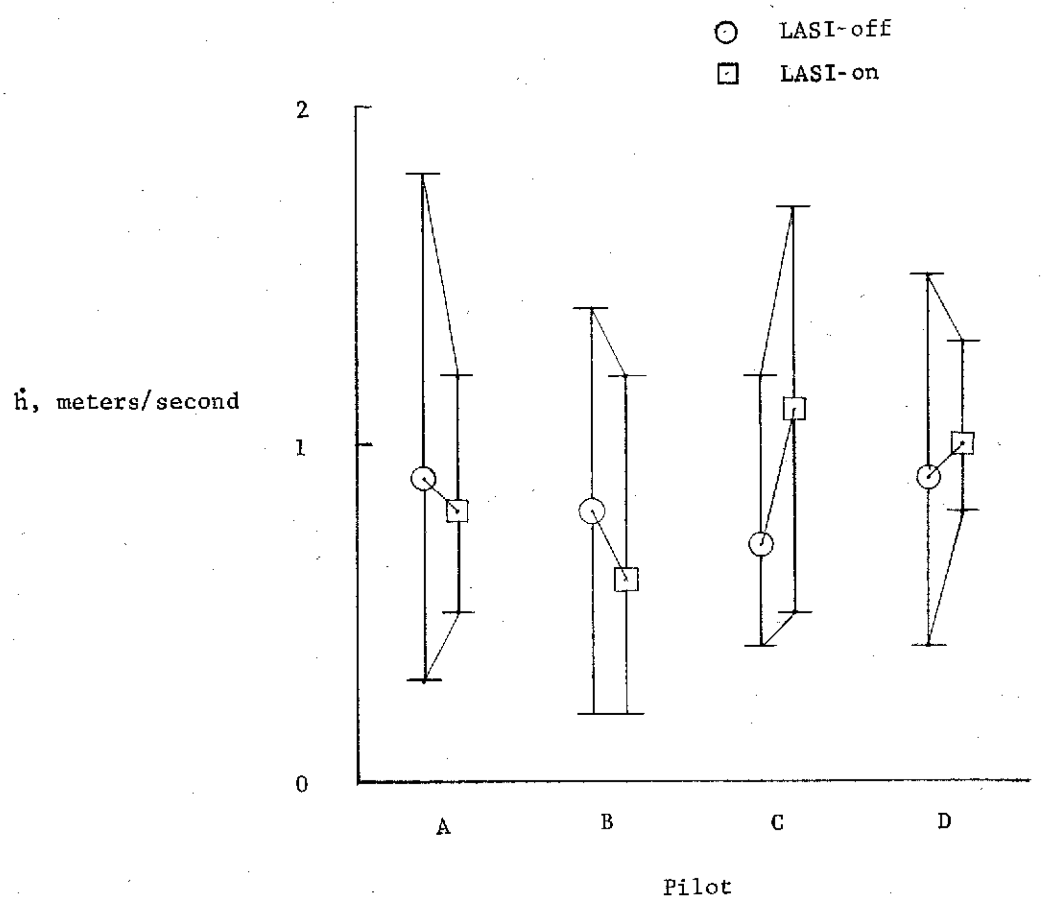
(a) Altitude at runway threshold.

Figure 6.- Comparison of measured values of pilot performance parameters h, x, $\dot{h}$, and $\dot{x}$ for the LASI-on and LASI-off conditions (data for all four initial conditions are combined).



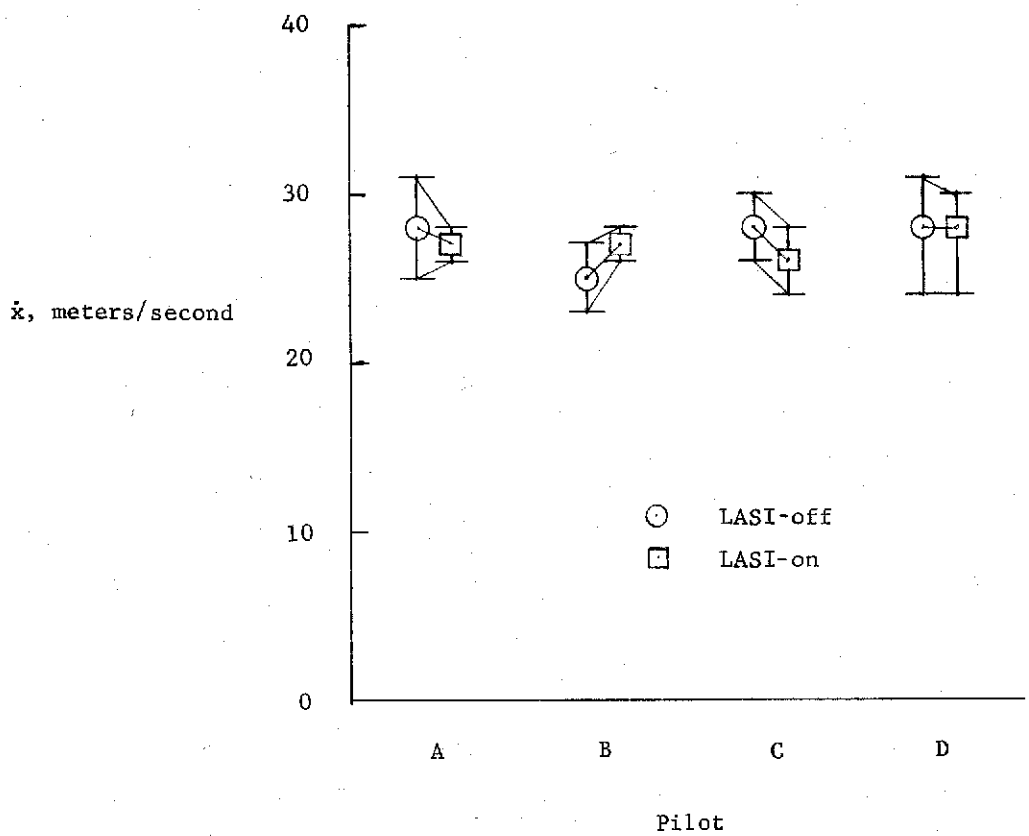
(b) Distance traveled along runway before touchdown.

Figure 6.- Continued.



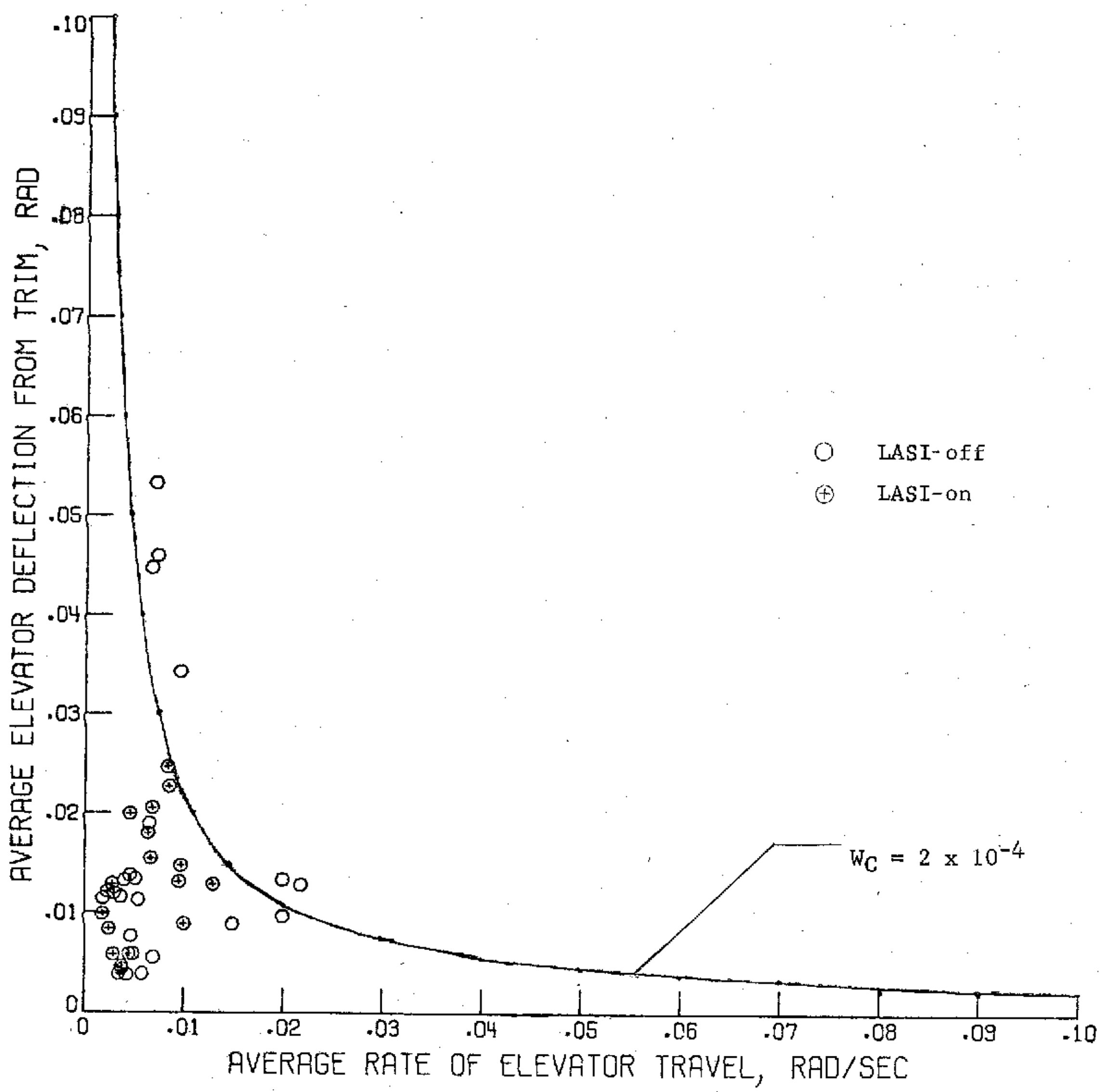
(c) Rate of descent at touchdown.

Figure 6.- Continued.



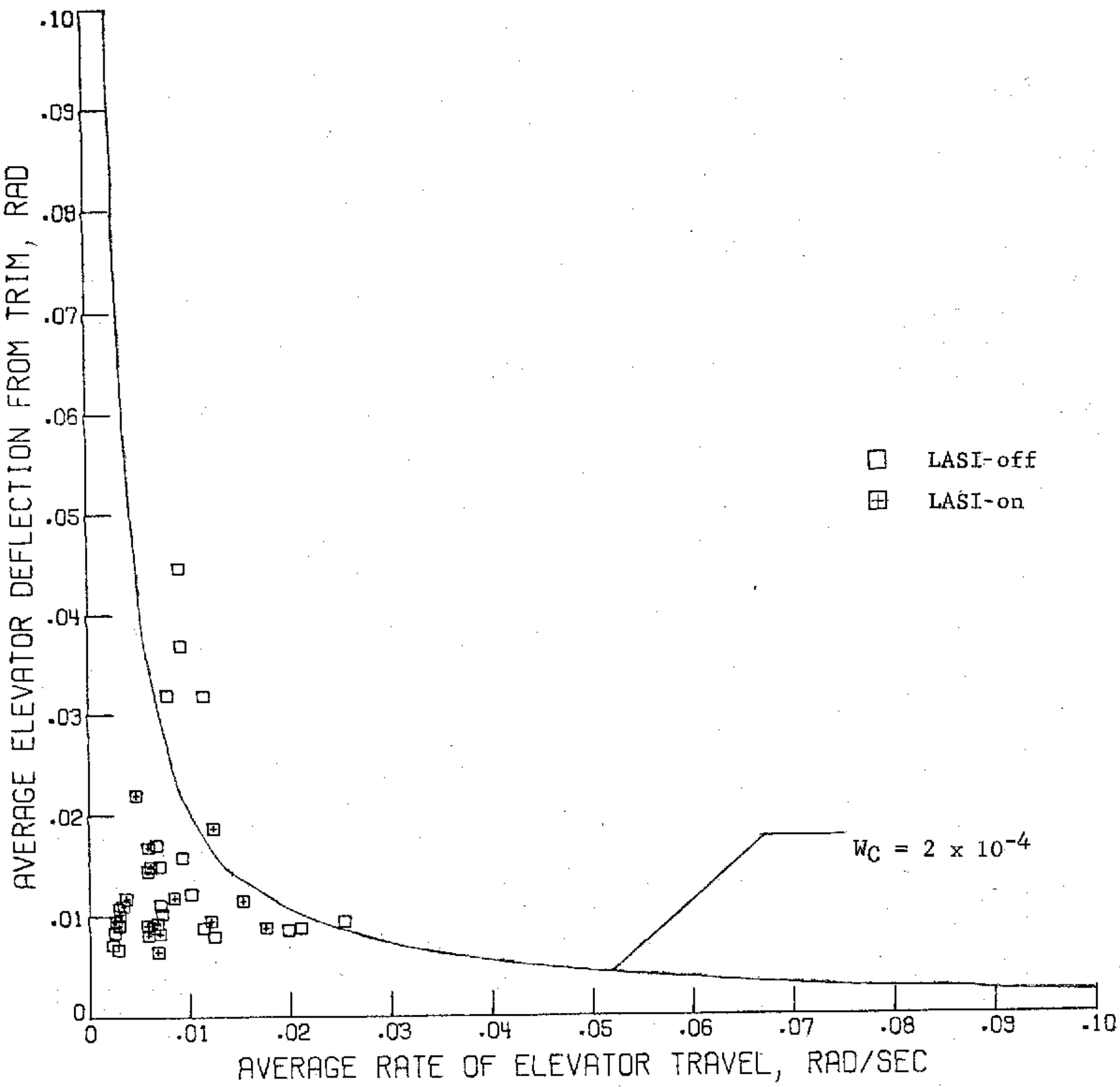
(d) Ground speed at touchdown.

Figure 6.- Concluded.



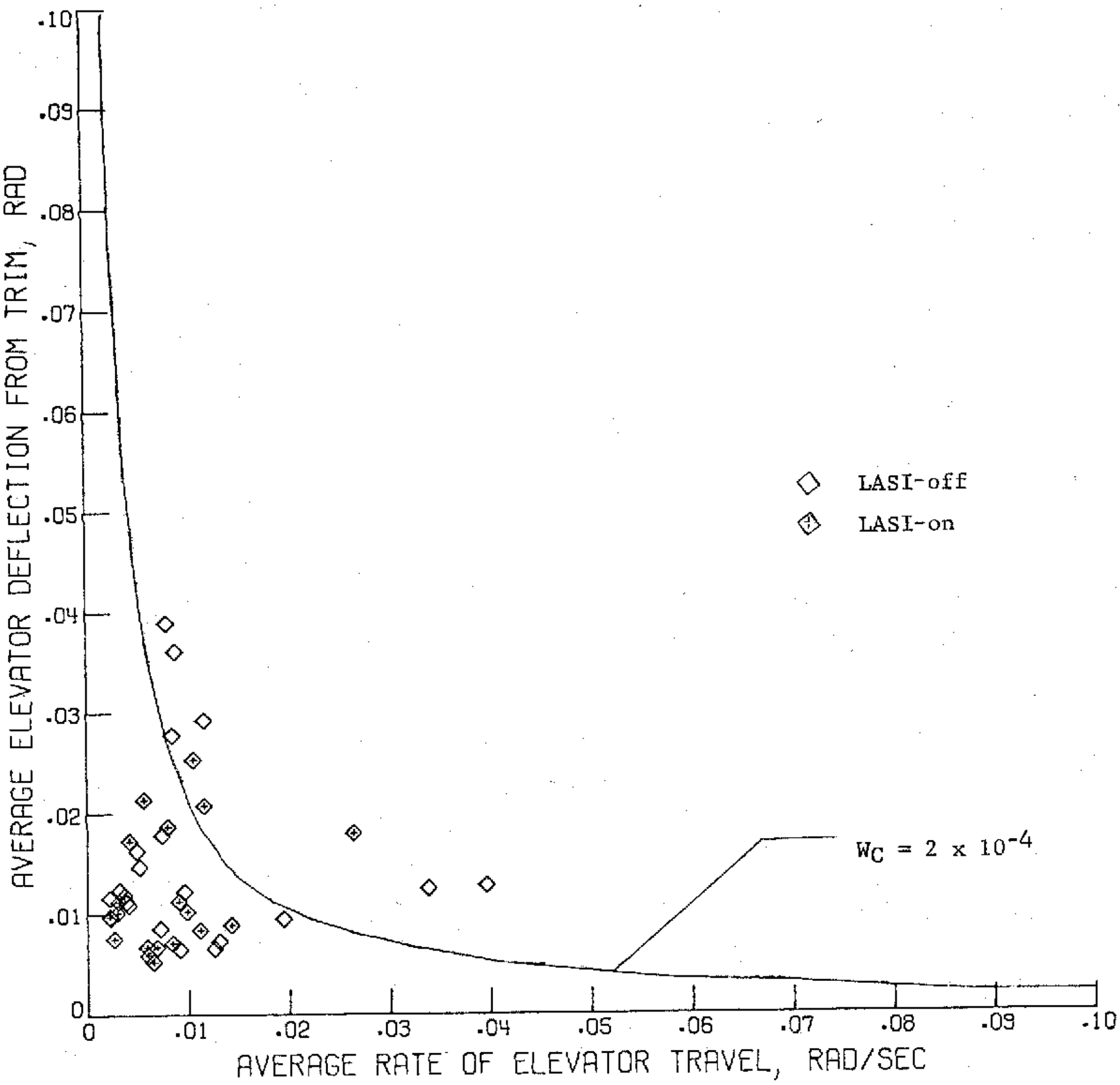
(a) Case I.

Figure 7.- Elevator workload parameters for LASI-on and LASI-off.



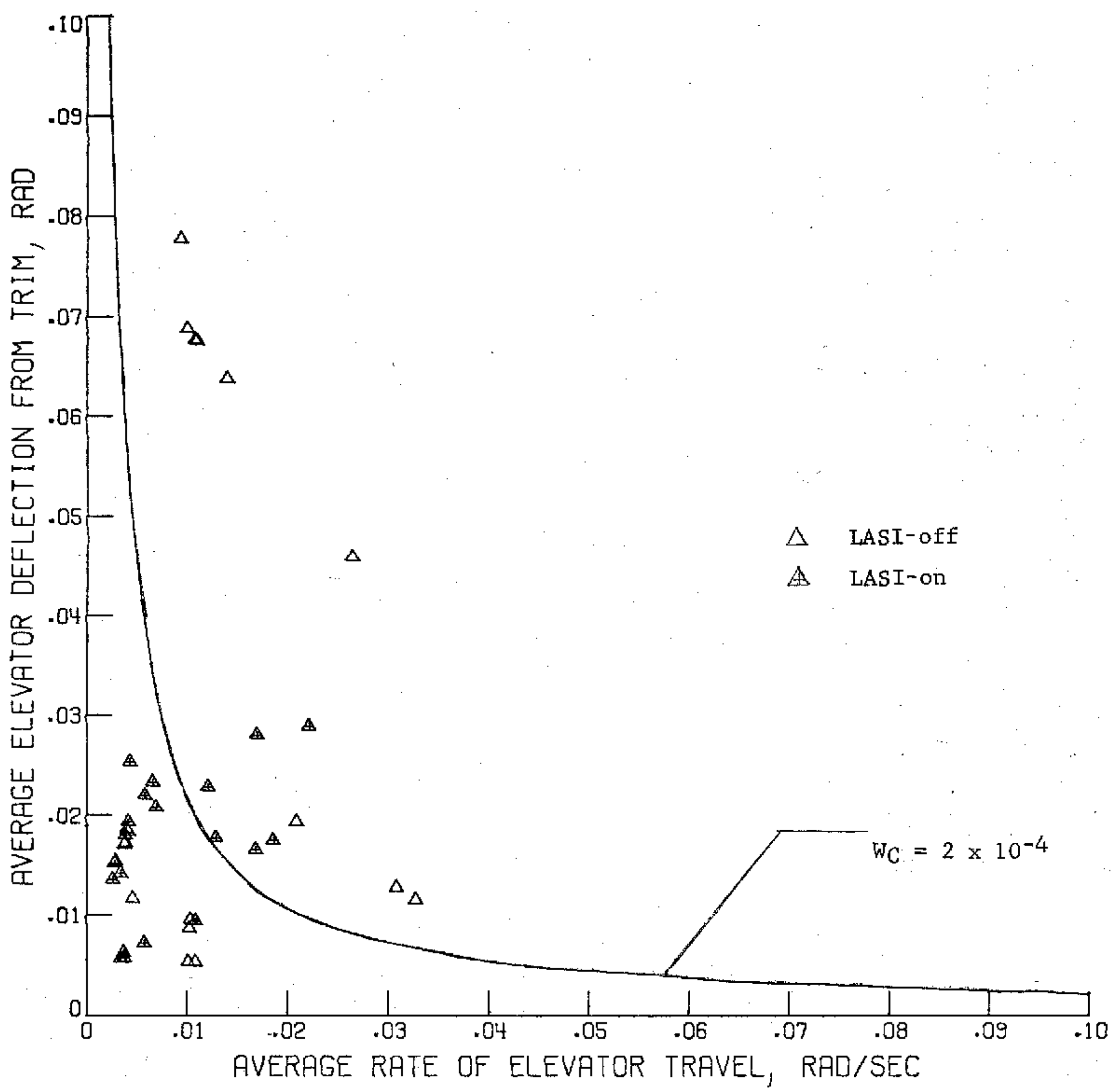
(b) Case II.

Figure 7.- Continued.



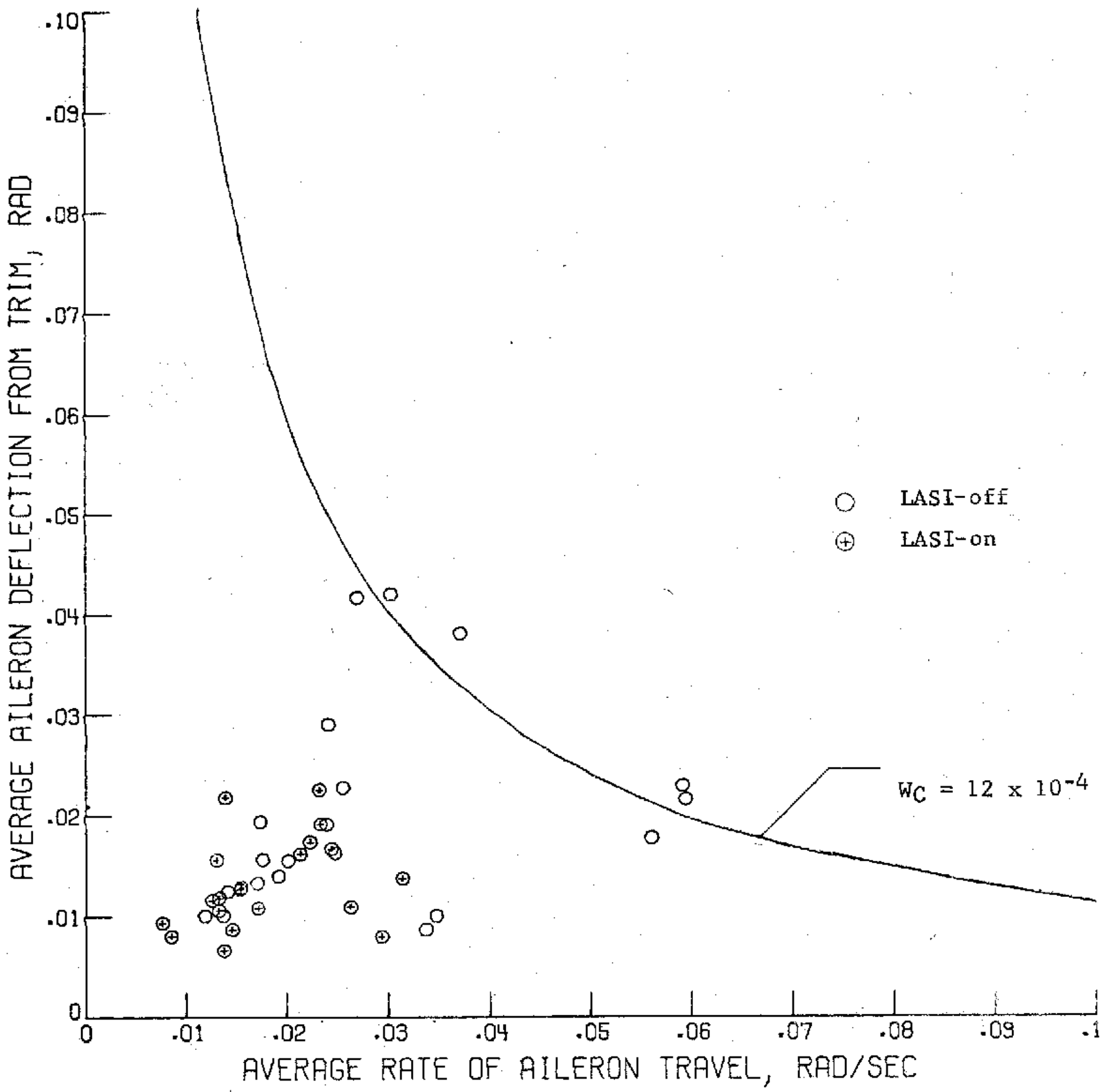
(c) Case III.

Figure 7.- Continued.



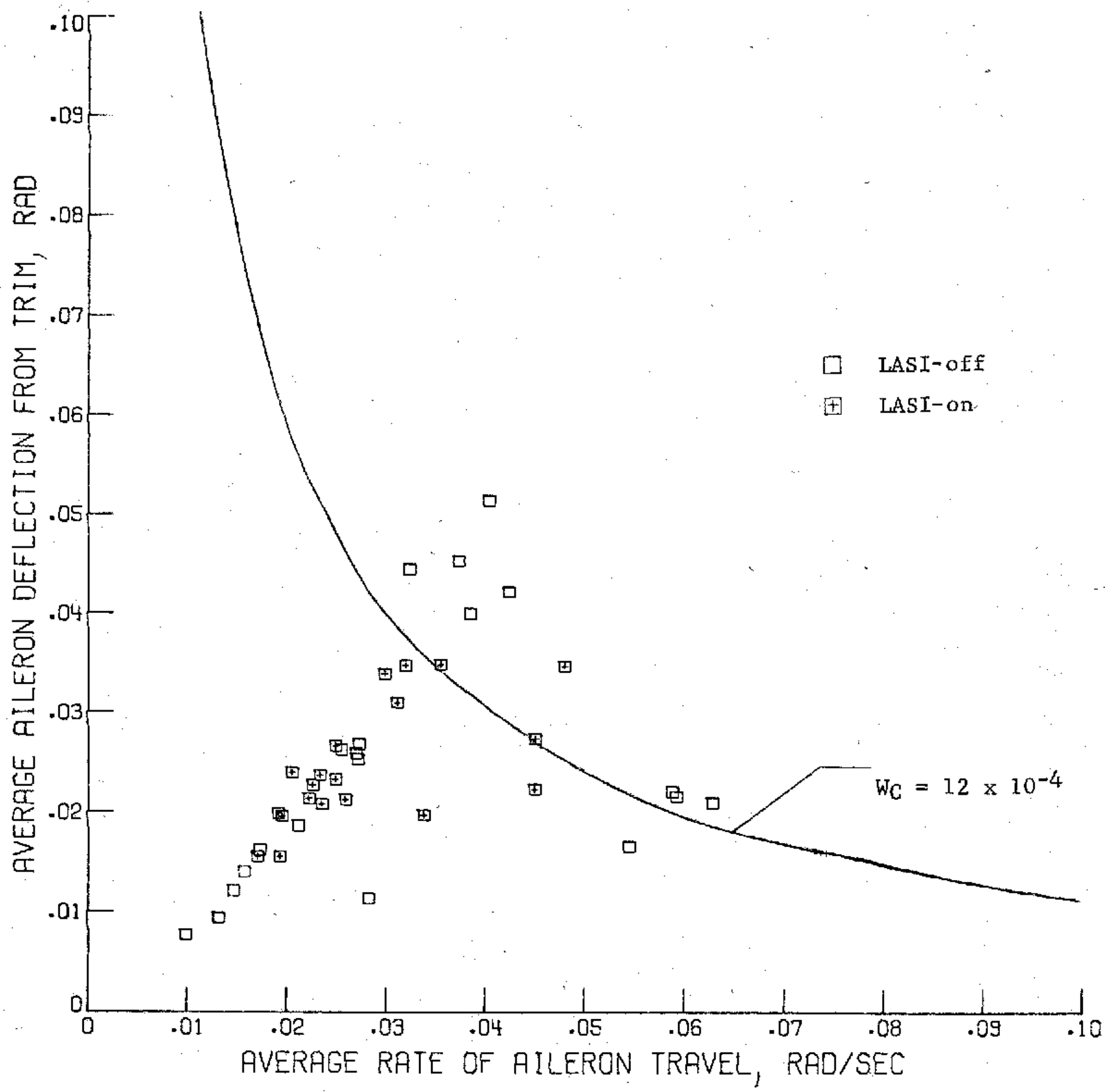
(d) Case IV.

Figure 7.- Concluded.



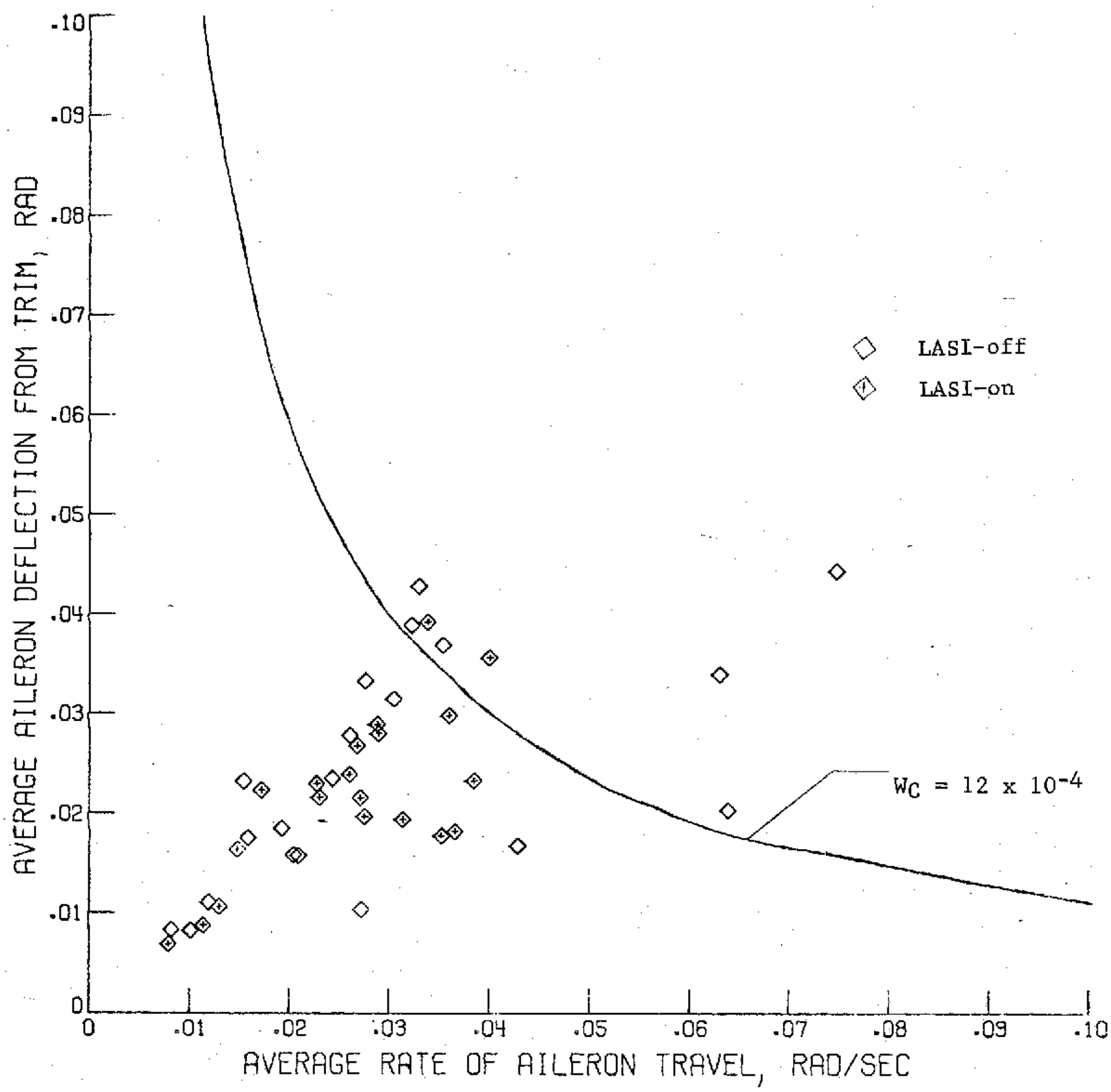
(a) Case I.

Figure 8.- Aileron workload parameters for LASI-on and LASI-off.



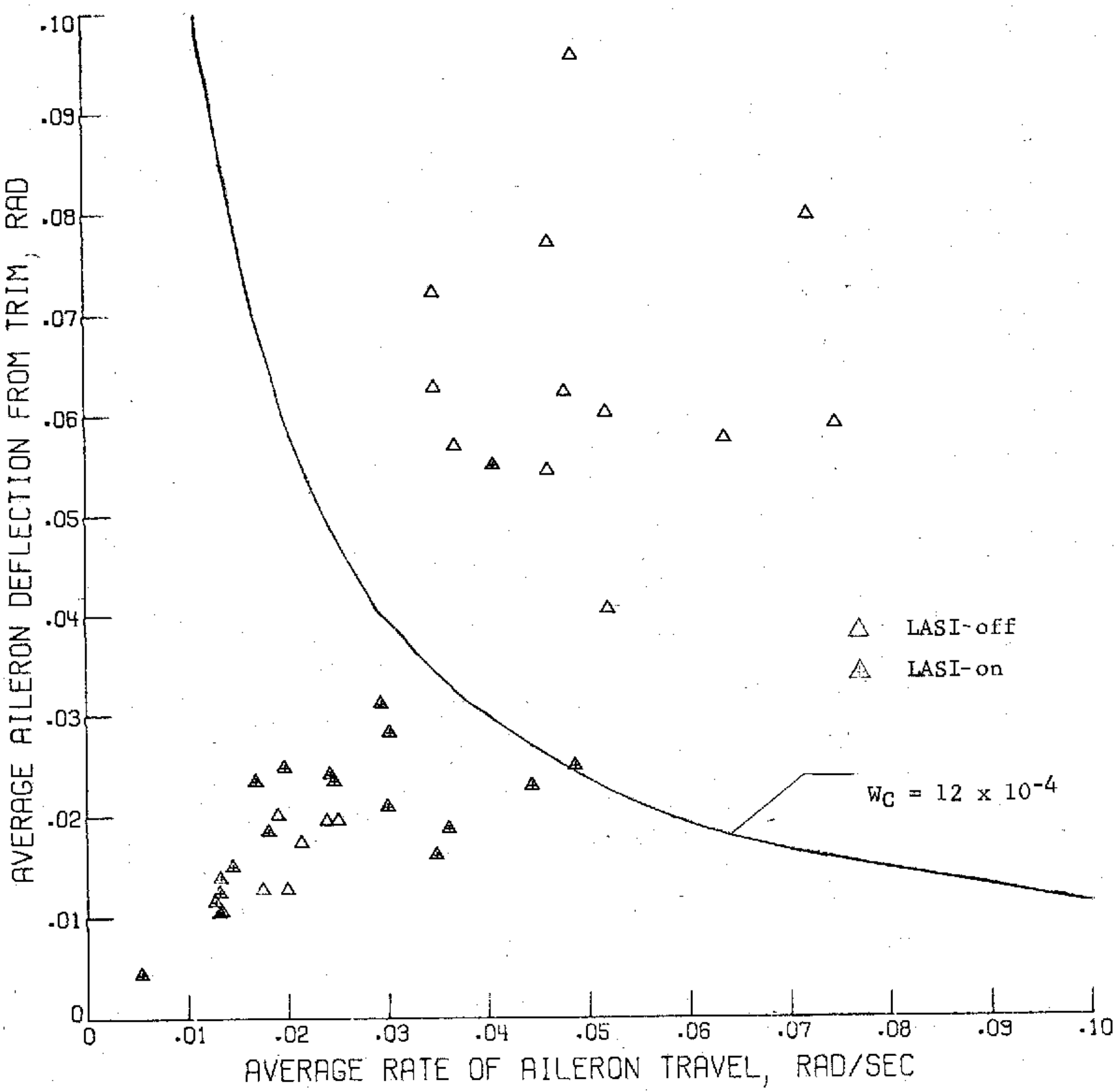
(b) Case II.

Figure 8.- Continued.



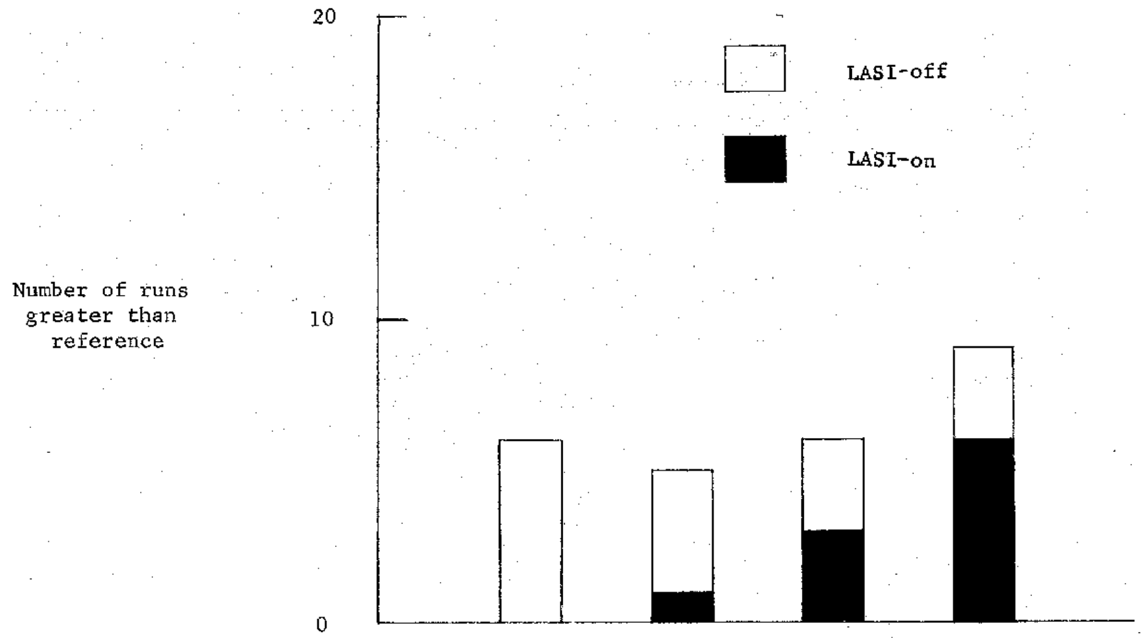
(c) Case III.

Figure 8.- Continued.

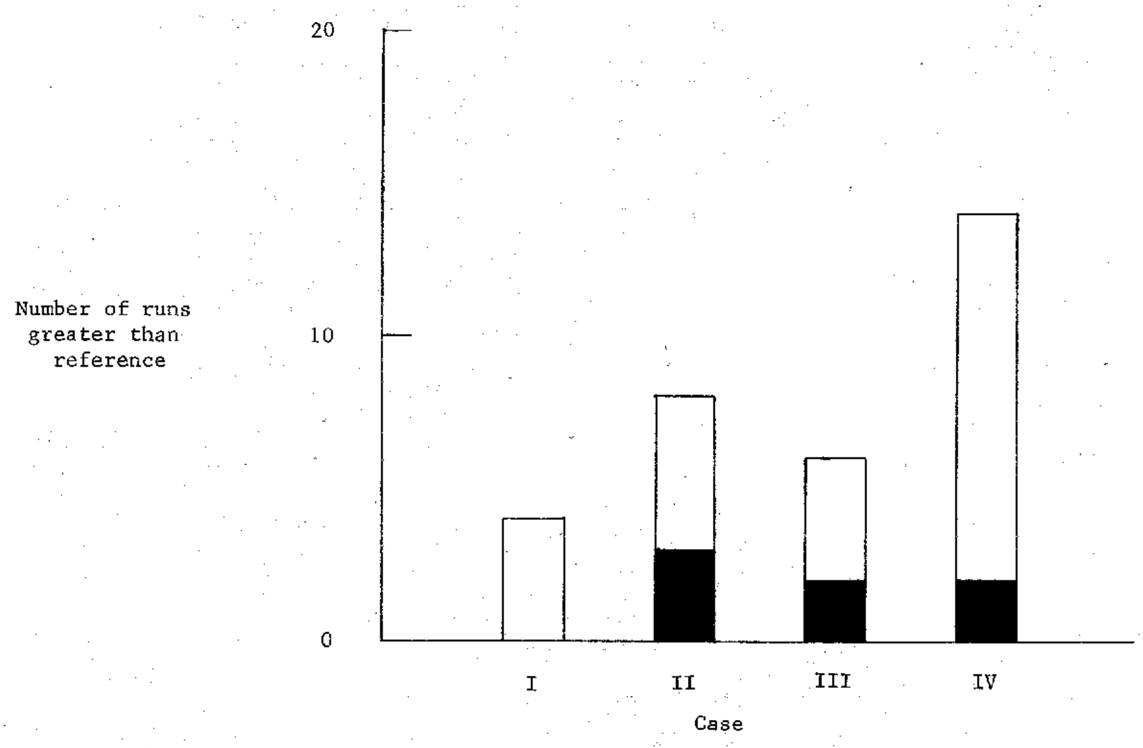


(d) Case IV.

Figure 8.- Concluded.



(a) Elevator.



(b) Aileron.

Figure 9.- The number of runs greater than the elevator and aileron reference curves (figs. 7 and 8) with the LASI-on and LASI-off for various initial conditions.

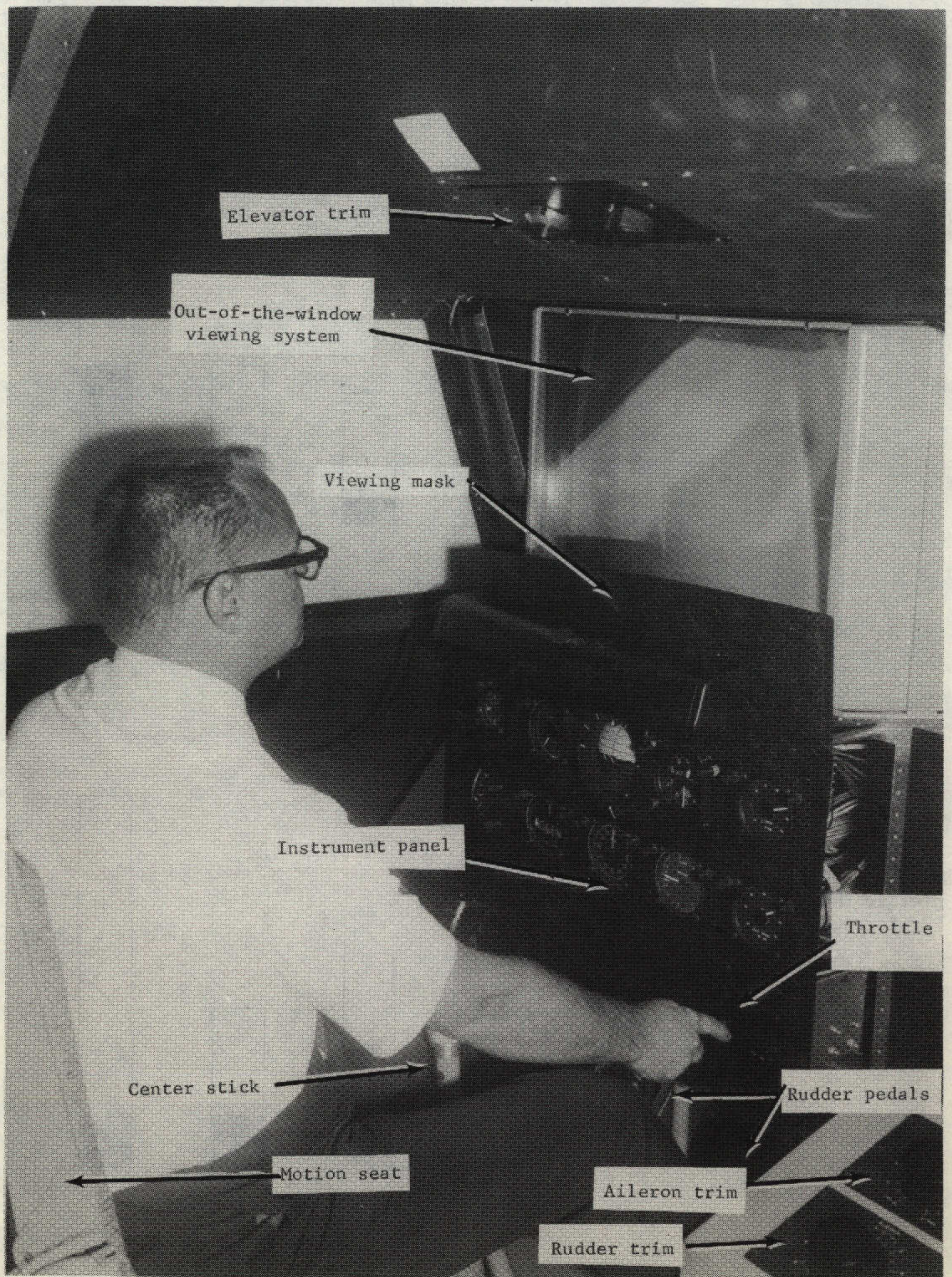


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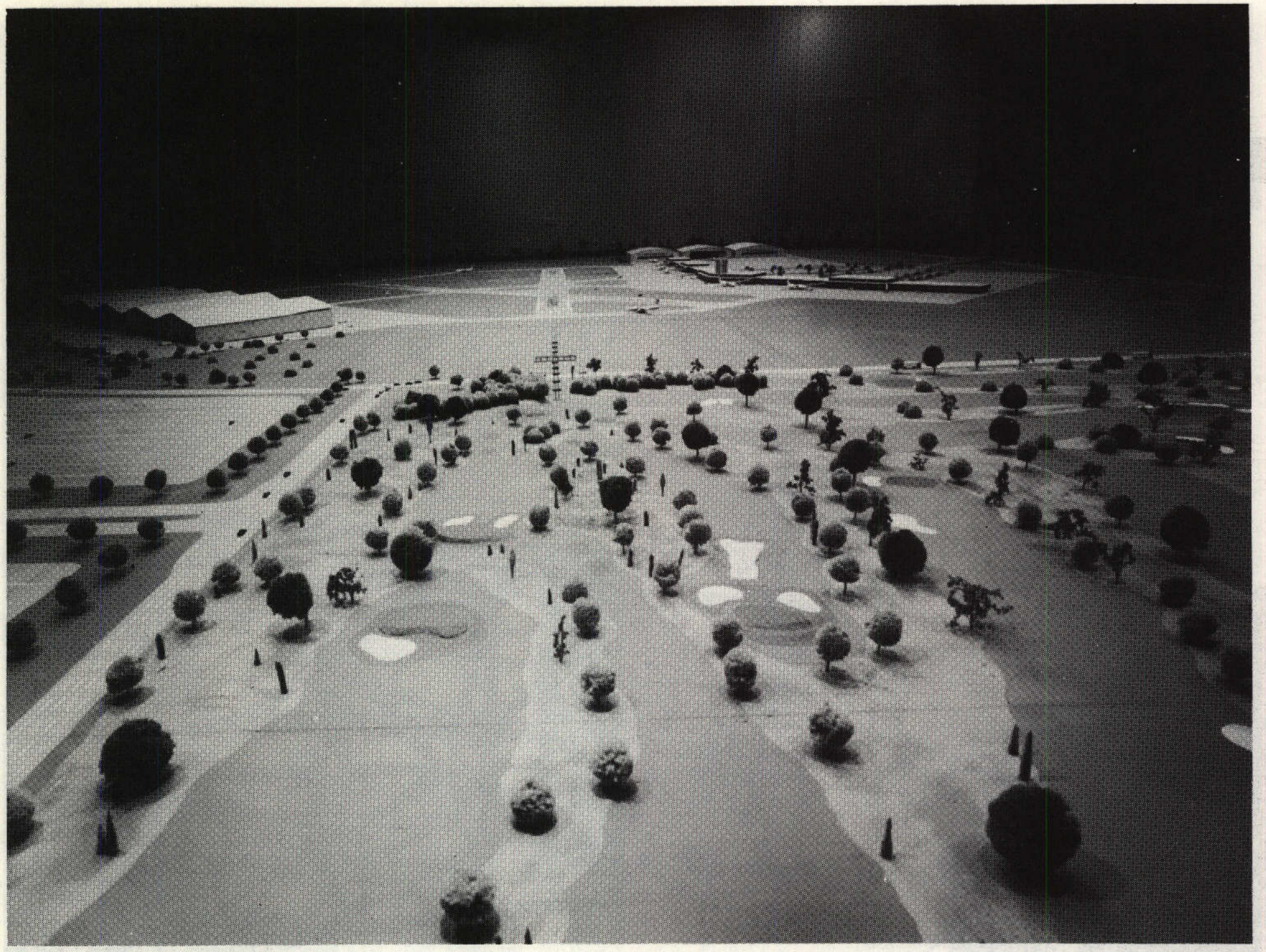
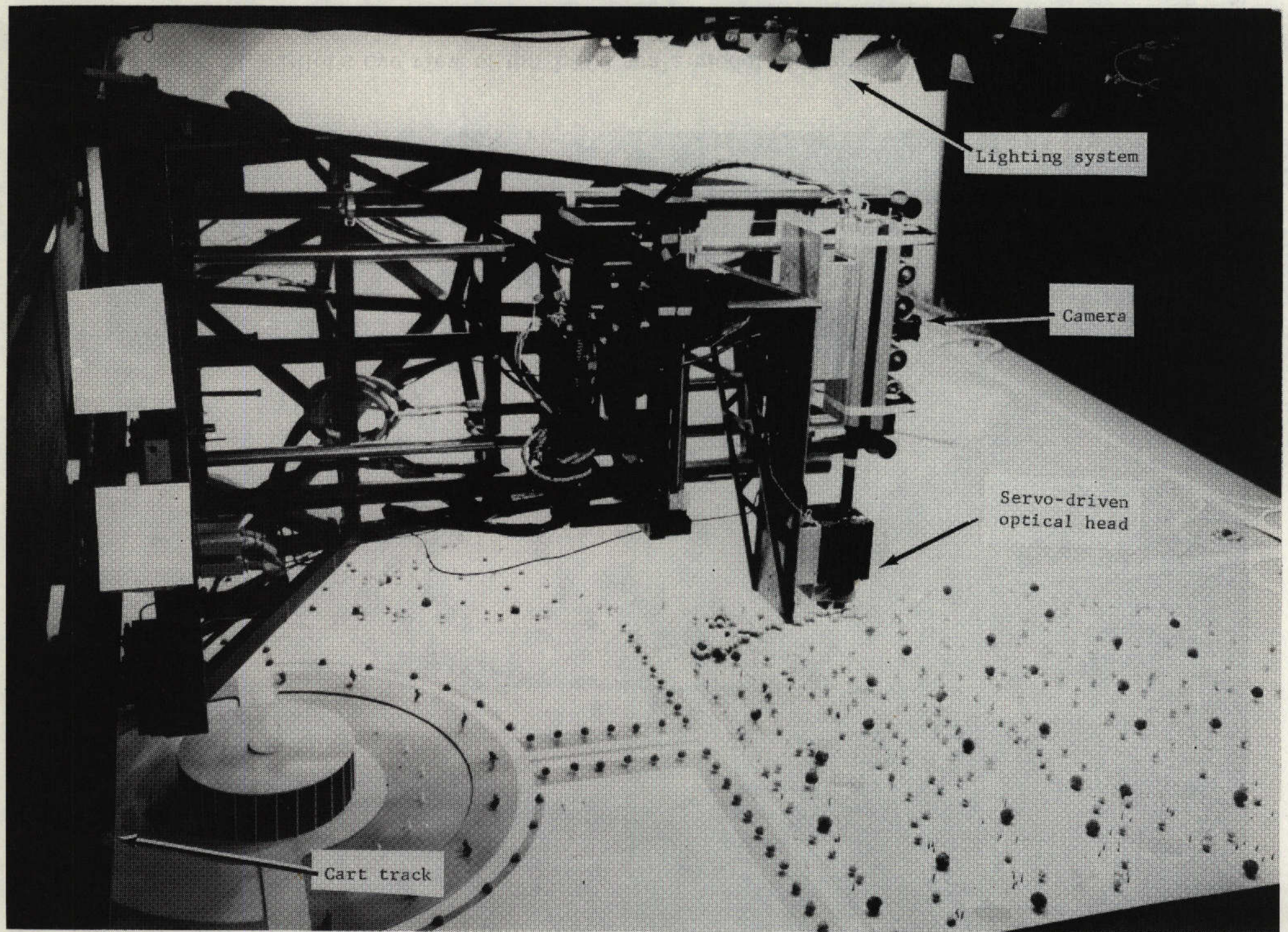
Figure 10.- View of the simulator cockpit showing the controls, instrument panel, and out-of-the-window viewing system.



L-71-4272

Figure 11.- Pilot's eye view of the 1:300 scale model of the airport as seen from a landing approach position on final leg for the active runway.



L-70-5683.1

Figure 12.- View of television camera and cart in a position given in figure 7. For convenience the model is mounted vertically.

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